An Examination of the Role of Explicit Knowledge in Sequence Learning

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

This study challenges current assumptions within the implicit learning field by investigating and highlighting the importance of the role of explicit knowledge in a sequence learning paradigm. It is argued that a fuller understanding of the role of explicit knowledge must be reached in order to make advances with implicit learning research. Explicit learning is often not fully investigated and declared too inadequate to explain the learning evidenced from performance measures. This leads to a potentially false conclusion that implicit learning has occurred. An indepth individual analysis of the degree and type of explicit knowledge was undertaken for participants who trained with a sequence of lights, a structured control, or a random control series. Sequence and structured control participants demonstrated explicit knowledge relevant to their training. Structured control participants evidenced explicit knowledge of relative frequencies of lights and transitions, whilst sequence participants did not. Sequence participants did show explicit knowledge of sequence chunks suggesting a tendency for explicit knowledge acquisition at the highest level of structure imposed on a sequence. The performance of a secondary tone-counting task during training did not produce a reduction in explicit knowledge, acting simply to slow participants' responses. Three direct tests were used to assess explicit knowledge. Comparison highlighted differences in sensitivity, but not in the content derived from the three tests. An attempt was made to replicate and extend Leadley's (1997) finding that explicit knowledge is reflected in diminished decision times during training. This was not accomplished, but suggestions were made for a future attempt to replicate this finding. Recommendations for further research into when explicit learning occurs, what information is amenable to explicit learning, and assessment methods, are outlined. The hope is for a realisation, within the sequence learning field, of the importance of a greater understanding of the role of explicit learning.

1.0 INTRODUCTION

1.1 Sequence Learning

An essential human skill, often taken for granted, is our ability to learn sequences. This ability is central to the learning of the many procedures that incorporate series of events, such as cooking, tying shoelaces, and programming your VCR.

This vital skill has been the focus of a wealth of research and literature. The typical paradigm for investigating sequence learning has involved four asterisks on a computer screen in set locations (denoted A, B, C, D for future reference) which appear one at a time according to a pre-determined sequence. This procedure was first used by Nissen and Bullemer (1987) with a 10-long repeating sequence (e.g. DBCACBDCBA) that was repeated ten times in each block of 100 trials. Participants were required to respond to the onset of each asterisk by using a designated finger to depress a set computer key for each of the four possible locations. This task is formally known as the serial reaction time task (SRT), as the latency between the onset of the asterisk and the depression of the response key is measured.

Sequence learning is typically assessed by one or both of two methods. The first involves the comparison of sequence participants' response latencies (total reaction times, hereafter TRTs) with participants who are presented with a random series of asterisks, (e.g. Perruchet & Amorim 1992). Participants in the random control group may show shorter TRTs as the experiment progresses due to practice of the task requirements. It is assumed that any further decrease in TRTs by the participants presented with a repeating sequence, over and above that shown by the random control participants, is due to learning of at least some of the sequence characteristics. A variation on this method is to intersperse random trials within a sequence and use performance on these trials as a control for sequence trials within each participant, (e.g. Stadler 1993).

The second method for assessing sequence learning is to discontinue the presentation of the sequence during the experiment and replace it with a random or different series of asterisks without informing the participant of the alteration, (e.g. Cohen, Ivry & Keele 1990). If participants have learned something about the sequence, then it is assumed that participants' TRTs will increase because sequence knowledge can no longer support the speeded responses.

Both of these methods for assessing whether learning of the sequence has occurred are known as indirect tests of learning. This is because of their reliance on performance speed measures rather than direct probes of explicit sequence knowledge.

Direct tests involve probing of sequence knowledge following SRT training. These may be in the form of a structured interview whereby participants may be asked if they had been presented with a sequence during training and if they could describe it, [e.g. Heuer & Schmidtke (1996), Curran & Keele (1993)]. Alternatively, participants may be required in a recognition task to differentiate between smaller chunks of the sequence and fabricated random chunks by indicating if the shorter series had been presented to them during the SRT (e.g. Stadler 1995). Yet another direct test involves asking the participant to respond to an asterisk by depressing the key associated with the asterisk location they thought would occur <u>next</u>, rather than by depressing the key corresponding to the current asterisk location, (e.g. Perruchet, Gallego & Savy 1990). This direct test is known as a prediction task, or alternatively as a generation task. A fourth option for a direct test is known as a free generate task and was developed by Perruchet and Amorim (1992). Here participants are given a small part of the sequence (two asterisks for example) and asked to continue depressing keys so that they produce a sequence which mimics the training sequence as closely as possible. The resulting series is then analysed to determine if the participant generated asterisks according to random chance performance, or if the generated series is a reflection of some knowledge pertaining to characteristics of the SRT sequence.

The focus of a large number of the studies relating to sequence learning centres on an apparent dissociation between the indirect and direct indicators of learning, (e.g. Jimenez, Mendez & Cleeremans 1996). In some studies, the indirect performance measures have been found to indicate sequence learning while the direct tests of sequence knowledge show no or little sequence learning. Thus, it has been postulated that the direct and indirect tests access different learning mechanisms. Direct tests are considered to be tests of explicit sequence knowledge. This dissociation has led some researchers to believe that the indirect tests of sequence knowledge must tap a knowledge store which is not readily amenable to conscious recollection, (e.g. Nissen & Bullemer 1987). This learning of a sequence (as determined from indirect tests) with insufficient explicit knowledge to account for performance (from direct tests) has been termed implicit learning.

Researchers have attempted to make use of this dissociation by suppressing the acquisition of explicit knowledge in order to study implicit learning. The typical method for suppressing explicit knowledge is via distraction whereby participants are required to perform a second task simultaneously with the SRT (hereafter secondary task). This secondary task usually incorporates the counting of high-pitched tones in a mixture of high and low-pitched tones, which are presented at the same rate as the primary stimulus. The assumption is that explicit knowledge will be suppressed or eliminated. As a result, a dissociation between direct and performance measures may occur, leading the researchers to the conclusion that implicit learning has been evidenced (e.g. Cohen et al 1990).

The majority of sequence learning investigations to date focus on verifying the existence of implicit learning as a phenomenon or the conditions necessary for the dissociation between implicit and explicit learning systems to occur, (e.g. McDowall, Lustig, & Parkin 1995). The main questions of interest have been 'what information can be learned implicitly?', and 'when does implicit learning occur?'. Very little research has addressed questions pertaining to the explicit learning of sequences. The belief in the existence of implicit learning has come about from, and is dependent on, the apparent deficit in explicit knowledge in the sequence learning studies. By-passing the investigation of the role of explicit sequence learning, to focus on what is considered implicit, seems premature until questions such as 'what information is learned explicitly?' and 'under what conditions does explicit sequence learning occur?' can be answered. In neglecting the importance of explicit knowledge one cannot be certain that the direct tests correctly ascertain the extent of explicit knowledge before concluding that a dissociation has occurred. Nor can one make assumptions regarding when explicit learning is less likely to occur, and therefore conclude that learning in these conditions must be implicit in nature.

1.2 Assessing Explicit Knowledge

As briefly outlined above, several direct test methods exist for assessing explicit sequence knowledge. However, numerous difficulties are associated with the use of these direct tests. The first relates to the time lapse between completing the SRT and attempting a direct test. There can be no guarantees that explicit sequence knowledge utilised and benefiting performance during the SRT has not been subject to some decay or interference before the completion of the direct test. This is particularly relevant to experiments using a transfer procedure to assess learning prior to direct test completion. An unobtrusive measure of explicit sequence knowledge, which occurs during SRT training, would counter this issue. Leadley (1997) argued that the SRT total response time is comprised of a decision time and a movement time, where the decision time component is a reflection of explicit knowledge. That is, improvements in decision times (as compared with controls) are due to explicit sequence knowledge and reflect a participant's ability to explicitly predict the continuation of the sequence.

The second problem pertains to the inability of many direct tests to capture a participant's entire wealth of explicit sequence knowledge, (Shanks & St. John 1994). Direct tests such as a structured interview that rely on participants' verbal reports of their knowledge result in an underestimate of explicit knowledge. This in turn leads researchers to claim a case for implicit learning, as there appears to be insufficient explicit knowledge to account for SRT performance. Reasons for a particular direct test failing to encapsulate explicit knowledge in its entirety can include participants omitting relevant information due to lack of confidence in the accuracy or relevancy of their knowledge. Direct tests vary in the amount of information that can be attained from their application. Structured interviews or verbal reports are considered as relatively insensitive measures as they do not result in as thorough an account of explicit knowledge as the free generate task (for example) on which participants are able to volunteer a greater amount of information. To overcome this concern, researchers can opt for a more sensitive explicit knowledge measure.

However, concerns also surround direct tests at the more sensitive extreme as it is believed by some that these tests may not be accessing purely explicit knowledge, (Cohen & Curran, 1993). In the recognition test for example, participants may be able to rate fragments as familiar due to the realisation that they were more fluid or rapid in their physical response to the fragment. That is, some of the more sensitive direct tests of explicit knowledge may yield more information because participants are influenced by processes that are implicit rather than entirely explicit in nature. The closer the direct test approximates the SRT the more likelihood of the direct test being impure. However, ensuring the context is as similar from SRT to direct test is one of the methods espoused by Jimenez et al (1996) to combat the above mentioned underestimation of explicit knowledge.

Given these conflicting concerns it is no wonder that, to date, there is no standardised assessment method for determining explicit sequence knowledge. One method which should perhaps be ruled out as a candidate for an appropriate direct test is the prediction test, sometimes known as the generation test (although distinct from the free generate task). To reiterate, this test involves asking the participant to respond to each stimulus by depressing the response key corresponding to the stimulus which they think appears next, (e.g. Frensch, Buchner & Lin, 1994). Firstly, because the correct prediction is always given on the next trial, participants are given continual feedback as to their accuracy. This provides a learning opportunity, and the number of correct responses could be indicative of this process rather than of the explicit knowledge a participant had on completion of the SRT and prior to the direct test commencement. To combat this argument researchers have done one of two things. The first is to look at savings in the time taken to learn the sequence during the test (e.g. Willingham, Nissen, & Bullemer, 1989). If participants who were presented with a sequence during SRT training show a steeper learning curve than their control counterparts then explicit knowledge must be the cause. However, if implicit learning occurred during the SRT for the sequence participants, then there is no way of telling whether this enhanced learning is due to implicit or explicit learning as the generation task when used in this manner resembles an indirect performance measure. A second tactic for utilising the prediction test is to withhold feedback regarding accuracy to prevent learning from occurring during the prediction task (e.g. Stadler, 1989). For example, six trials may be presented and the participant is required to predict the seventh. This method has been criticised, as forgetting is likely to occur during the course of the test. One could examine only the first few trials of the test to combat this criticism, but this method provides too little data on which to base such judgements as how much explicit learning had occurred, and what information had been learned. The prediction test appears to be far from ideal for examining many of the important issues surrounding the acquisition of explicit knowledge.

Another problematic method which has been overlooked in some studies is to make the aim of the direct test explicit in the instructions given to participants on commencement of the direct test, as noted by Perruchet and Amorim (1992), and Shanks and St. John (1994). Participants are more likely to utilise their explicit knowledge of the SRT sequence characteristics if they are told that the rationale behind the test is to access that form of knowledge. In studies where participants perform the direst test without realising its purpose, it would seem possible that they do not fully use their explicit knowledge and may attempt to continue to rely on an implicit knowledge base if it proved successful in the SRT.

Shanks and St. John (1994) raise the point that direct tests are formed to examine whether participants have knowledge about a restricted set of sequence characteristics that researchers think are important. Participants are tested to determine if they have explicit knowledge of the entire sequence or of sequence chunks. Is the assumption that knowledge at the sequence chunks level is the only useful knowledge for SRT performance a valid one? It may be more useful to steer away from a narrow focus to determine exactly what information inherent to a sequence is prone to explicit learning. Again underestimates of explicit knowledge may potentiate false claims regarding the existence or extent of implicit learning.

If participants are showing learning in their SRT performance which is not entirely due to learning components of the sequence, then what information could they be learning? Learning about the frequencies of events within the sequence may lead participants to exhibit enhanced performance in the absence of knowledge of sequence chunks or complex rules, (e.g. Perruchet et al 1990). Reed and Johnson (1994) claim that reversals of stimuli within the sequence (e.g. ACA) are particularly salient and are likely to be readily learned. Cohen et al (1990) posit that unique associations (where stimulus 'A' is always followed by 'D' for example) act as 'flags'. These are easier to learn and are needed for effective encoding of adjacent ambiguous transitions (where either 'E' or 'C' can follow the occurrence of stimulus 'B', for example). Determining whether event frequencies, reversals, or unique associations are particularly amenable to explicit learning, and could account for facilitated SRT performance, could be invaluable.

Yet another concern with direct tests is that researchers tend to examine explicit knowledge over a whole group of participants. That is the experimenter may look to determine if the participants in a condition as a whole are aware or unaware of the sequence, (for example Lewicki, Hill & Bizot 1988). The researcher may ascertain that as a group, the participants are unaware of the sequence (or a specific sequence component), while it is possible that a subgroup of the participants have some relevant explicit knowledge, which is lost in this process. Alternatively, researchers may group participants into those with and those without sequence knowledge (Stadler 1993 and Stadler 1995, for examples), and compare these two groups on response characteristics (e.g. TRT). Knowledge of sequence characteristics is likely to occur on a continuum with some people having no explicit knowledge, some with a little, and some with a great deal. On this basis the grouping of people into aware or unaware does not appear to be appropriate. It may prove more useful to examine which sources of sequence information a participant is aware of, and then compare the response characteristics with those parts of the sequence they do not have explicit knowledge about. Another method sometimes used in past research has examined TRTs or explicit knowledge reports over a particular group to see which parts of the sequence the group is aware of (See Perruchet et al 1990 and Perruchet & Amorim 1992, for examples). Is it not reasonable that individual participants organise sequences differently, or find different parts of a sequence salient, and therefore have explicit knowledge of distinct and differing sequence characteristics? An individual approach to examining explicit knowledge may be the most appropriate, comparing response characteristics for the particular sequence components associated with and without explicit knowledge, within each participant.

1.3 The Current Experiment

The present study addresses some of the inadequacies within the sequence learning domain by closely examining the role of explicit learning. The main focus of the current sequence learning experiment is to more accurately assess the extent of explicit knowledge, and determine what information is learned explicitly.

Examining what information is learned explicitly is central to this study. Simple frequency information with regard to the relative occurrence of each stimulus and each transition between stimuli may be learned explicitly and may underlie enhanced SRT performance. That is, participants may be learning, for example, that the stimuli 'A' and 'D' occur more often, as does the 'DA' movement. Additionally, if reversals ('ADA' for example) are particularly salient, then participants may demonstrate explicit knowledge associated specifically with these patterns. This knowledge, in the absence of more complex sequence knowledge, may be sufficient to differentiate sequence participants from random controls. This issue regarding the existence and role of explicit frequency information is addressed by the use of several methods in this thesis.

In seeking explicit knowledge in this study, the search is not restricted solely to the learning of sequence parts or of the whole sequence. Participants are subjected to direct tests, which are sensitive to explicit frequency knowledge. Three direct tests for explicit knowledge are used. In the structured interview, participants are questioned about their explicit sequence knowledge, including prompts intended to access frequency information. A free generate task is used also, where the participants are asked to generate a series that is as similar as possible to that experienced during training. Analyses can then occur to determine if the generated series reflects the frequencies of events and transitions in the sequence, and whether participants are able to volunteer sequence chunks. Thirdly, a recognition task was used. In the past, performance on the recognition test could be enhanced if a participant had explicit frequency information, in the absence of sequence knowledge. The recognition test employed in the current study is designed so that frequency information cannot lead to enhanced performance. The recognition test foils (chunks not experienced during training) incorporated only movements that were actually encountered in training. The foils combined these movements in combinations that had not previously been encountered. If participants are learning only which movements occur and which do not (frequency information), then they should not be able to differentiate sequence chunks from foil alternatives.

In the traditional sequence learning studies control participants were presented with a random series of stimuli. More recently Reed and Johnson (1994), Shanks and St. John (1994) and Shanks, Green, and Kolodny (1994) have recognised that to determine if sequence information, as opposed to frequency information, is being learned then the control should not be random. Rather, it should reflect the frequencies of events in the sequence. If participants are learning information beyond simple frequencies then sequence participants should show learning superior to that of these structured control participants. This experiment uses both random and structured control sequences. The use of the structured control (matching frequencies) is appropriate if one is searching solely for evidence of sequence knowledge, but determining whether frequency information is learned is a valid contribution in itself. The use of both random and structured control sequences allows one to determine if sequence participants learn only frequency information, only sequence chunks or both types of information.

This allows a replication and extension of Shanks et al (1994) experiment that incorporated both forms of controls. They found that sequence participants who demonstrated 'full-knowledge' on a structured interview performed quicker in the SRT than the structured control participants. Their explicit sequence knowledge correlated with SRT performance that demonstrated learning above frequency level information. Sequence participants categorised as having 'no-knowledge' from the interview could not be differentiated from the structured control participants in terms of SRT performance. Both structured control and 'no-knowledge' participants demonstrated learning by responding more rapidly than random control participants in the SRT. These findings could allude to some sequence participants having explicit sequence knowledge that benefited their SRT performance, and the sequence participants without explicit knowledge having implicitly learned the relative frequencies incorporated in the sequence. However, categorising participants as 'having explicit knowledge' and those 'without explicit knowledge' is not as informative as a detailed analysis within each participant. Additionally, making this distinction solely on the basis of a relatively insensitive structured interview task should be cautioned against. This experiment endeavours to undertake a closer examination of participants' explicit knowledge by using a range of direct tests and examining explicit knowledge at an individual within-participant level. How the explicit knowledge evidenced in this manner relates to learning demonstrated from the SRT is then examined.

It should be noted that the definition of relative frequency information in this study diverges slightly from that of Reed and Johnson (1994). Frequency information in this experiment is primarily restricted to the relative occurrence of individual stimuli positions, and of transitions between these positions. Reversals (ACA for example) are also informally considered. Reed and Johnson on the other hand consider frequency information according to a larger variety of proposed indices for matching the repeating and structured control sequences. These include such indices as the rate of full coverage, which refers to the average number of stimulus presentations required in order for all stimulus locations to be experienced, (for example, ADACBDE takes seven stimuli presentations before all lights A-E are presented).

This experiment has taken a simpler definition of relative frequency information more in line with the scope of a thesis. This experiment attempts to address current inadequacies in the sequence learning literature. Complex analyses are performed in order to link frequency information to individual performance measures. Traditionally, researchers work from a simple focus to provide an initial phenomenon. This finding then results in the provision of a base on which more complicated future research can build. Any findings relating to simpler frequency information may in future be found to pertain also to more complex frequency information measures.

Additionally, in determining which information is amenable to explicit knowledge, the issue of defining relative frequency information may become one of psychological reality. That is, is the 'length of full coverage' a concept that an ordinary person would think of and utilise in the SRT task? We do know from other literatures, such as human matching law studies, (Conger & Killeen 1974, and Bradshaw, Szabadi & Bevan 1979) that people are responsive to relative frequencies and transition contingencies, so we might reasonably expect the same in the SRT task. Reed and Johnson (1994) were concerned with producing a control capable of isolating unique sequence knowledge, but this experiment also attempts to define frequency and other types of information that people may explicitly use when sequence learning.

Also, researchers can construct complex accounts of behaviour which can, when more closely examined, be explained with simpler determinants, (e.g. Perruchet et al 1990 found that simple frequency knowledge rather than the implicit learning of complex rules could account for facilitated performance in Lewicki et al's 1988 experiment). It could be that more complex relative frequency indices are consequent upon the likes of the relative frequency of the locations or transitions, the uniqueness of transitions ('A' is only ever followed be 'C', for example), reversals, stimuli presented on the left versus right side of the apparatus, or small versus large response movements, for example. These phenomena appear to be more amenable to conscious realisation than complex measures such as rate of full coverage.

Another approach taken in this study to better examine explicit knowledge was to select three direct tests to give a range of assessment tools, varying in their degree of sensitivity. Different conclusions from the multitude of studies in the sequence learning literature may in part be due to the propensity for different tests to yield differing conclusions. Three tests were used in this study to enable a loose comparison of their results, and to attempt to safe guard against the above-mentioned criticisms levelled against the various tests alone. The prediction test was not used, for the reasons already outlined. However, the recognition test was selected because it can be fine-tuned to eliminate the benefits of explicit frequency knowledge. The free generation task was used because of its ability to expose both frequency and sequence-chunk knowledge. The structured interview, whilst considered unreliable and insensitive, was added to supplement the above tests as it provides participants the opportunity to outline explicit knowledge they have which is not relevant to, and would not be detected by, the recognition and generate tasks. All tests are presented in a manner which explicitly links the direct test with information regarding the previously performed SRT, and instructions outline the aim of the tests as providing as much information about their knowledge of this SRT training as possible. Use of a transfer task was avoided in this experiment. The preference was to avoid retroactive interfering of transfer tasks with explicit knowledge used in the SRT.

The use of a new non-intrusive measure of testing for explicit knowledge, designed by Leadley (1997), is trialed in this experiment. Unlike the direct tests above, monitoring decision time during the process of the SRT enables researchers to assess explicit knowledge at the time of its use rather than after the event. As outlined above, Leadley posits that decreases in decision time occur if explicit knowledge is present. This method could be invaluable in that it could highlight exactly which information is associated with explicit knowledge. A search for the particular sequence components that exhibit decreases in decision times could answer this important question. This experiment serves also as an attempt to replicate Leadley's (1997) findings linking decision time to explicit knowledge. If explicit knowledge volunteered in the direct tests aligns with decreases in decision times for those sequence components then it is likely that Leadley's supposition that decision times reflect predictive or explicit knowledge is valid.

These comparisons between decision times and direct test information are made at an individual level. This is because all attempts are made to ensure the methods used in this study are sensitive to all explicit knowledge that may be used by participants to enhance their SRT performance. This includes analysing each individual's account of explicit knowledge, rather than averaging over groups or assuming that participants will have explicit knowledge of the same sequence information. In addition to the standard group analyses, explicit knowledge is assessed for each participant, and decision time comparisons made between information that has, and information that has not, been learned explicitly for that person.

Another facet of this study investigating explicit sequence knowledge relates to the role of the secondary task. The secondary task is typically utilised in sequence learning studies to decrease or eliminate explicit knowledge acquisition so that implicit learning can be more fully accessible, (e.g. Frensch et al 1994, McDowall et al 1995). Conditions with and without a secondary task are present in this study to assess both the degree to which explicit knowledge is suppressed and exactly which type of explicit knowledge is affected by the secondary task. It is the hope that a fuller understanding of the exact effects of a secondary task on explicit knowledge will be reached. This would seem desirable as the task is currently used as a method for manipulating explicit knowledge without this relevant knowledge. Determining whether the secondary task does meet its objective of decreasing explicit knowledge is vital.

Another objective of this study was not only to validate Leadley's (1997) link between decision time and explicit knowledge, but also to generalise this result. Leadley used a response task, which differed slightly from that used in a typical SRT procedure. In order to effectively separate and measure movement time and decision time, Leadley asked participants to use only one finger for all their responses. Participants were required to commence with their finger on a key (the home key), which was equidistant from all response keys. Participants then responded to the stimulus (light) by pressing the appropriate response key and then returning to the original home key ready to respond to the following stimulus. Decision time was measured as the time taken for participants to release the home key after stimulus-onset. Movement time corresponded to the time from the release of the home key to the depression of the response key.

The task used by Leadley (1997) was unique. However, relating her results to those found from the standard task may be difficult given the differences in task requirements. This study uses a response procedure, which can perhaps be considered as intermediate between Leadley's task and the standard SRT task (first used by Nissen & Bullemer 1987). Should Leadley's results extend to a task that is more similar to the standard SRT task used in sequence learning, then her results and conclusions are strengthened. Like Leadley's study, participants in this experiment are required to use only one finger for responding in the SRT. Unlike Leadley's study and similar to the standard SRT task, a home key is not incorporated. As for the standard procedure, this meant that movement time could not be accurately assessed. This was not a concern as movement time is not central to the objectives of this study. The response keys and stimuli are arranged in an arc and participants are required to respond to each stimulus as it illuminates by depressing the corresponding response key. Decision time is measured from stimulus onset, and is the time taken to release one response key in order to respond to the next. (See Figure 2.40, page 26 for further detail.)

It was hoped that this task, which like Leadley's is unique, would aid in bridging the gap between the contrasting standard SRT requirements and Leadley's task. This study aims to generalise and extend the finding found in Leadley's (1997) study that decision time reflects explicit knowledge.

To summarise, this thesis attempts to:

a) Determine the extent of explicit knowledge in a sequence paradigm,

b) Ascertain which information is learned explicitly,

c) Examine the effects of the secondary task on explicit sequence knowledge,

d) Provide an opportunity for an informal comparison of three explicit knowledge direct tests,

e) Generalise and extend Leadley's (1997) link between decision time and explicit sequence knowledge.

2.0 METHOD

2.1 Participants

Eighty adults (44 male, 36 female) ranging in age from 16 to 59 years (mean age 24 years) were randomly assigned, ten each, to eight experimental conditions. Most were University of Canterbury students, the remainder were drawn from a variety of occupations. Participants received a chocolate fish, a can of coke, and a lottery ticket for their participation.

2.2 Experimental Design

The following independent variables were manipulated.

1. The kind of training series presented. These were repeated sequence, structured control, and random control.
2. The requirement to complete a secondary tone-counting task or no tone-counting.
3. The type of direct test of explicit knowledge undertaken upon completion of the SRT training. All participants were questioned concerning knowledge of their training series. Additionally, most participants also completed a generation task, with the exception of half of the sequence groups, who instead completed a recognition task. The recognition task was not applied to participants from either of the control conditions as more useful information could be gleaned from efforts to replicate the information inherent in their SRT training, than to ask them to recognise parts of a sequence they had not encountered. The complete breakdown of experimental conditions is given in Table 2.20.

Table 2.20: Eight experimental groups were used to combine the three independent variables of the experiment.

	SECONDARY TASK	NO SECONDARY TASK
SEQUENCE GROUP	Recognition Test	Recognition Test
SEQUENCE GROUP	Generate Task	Generate Task
STRUCTURED CONTROL	Generate Task	Generate Task
RANDOM CONTROL	Generate Task	Generate Task

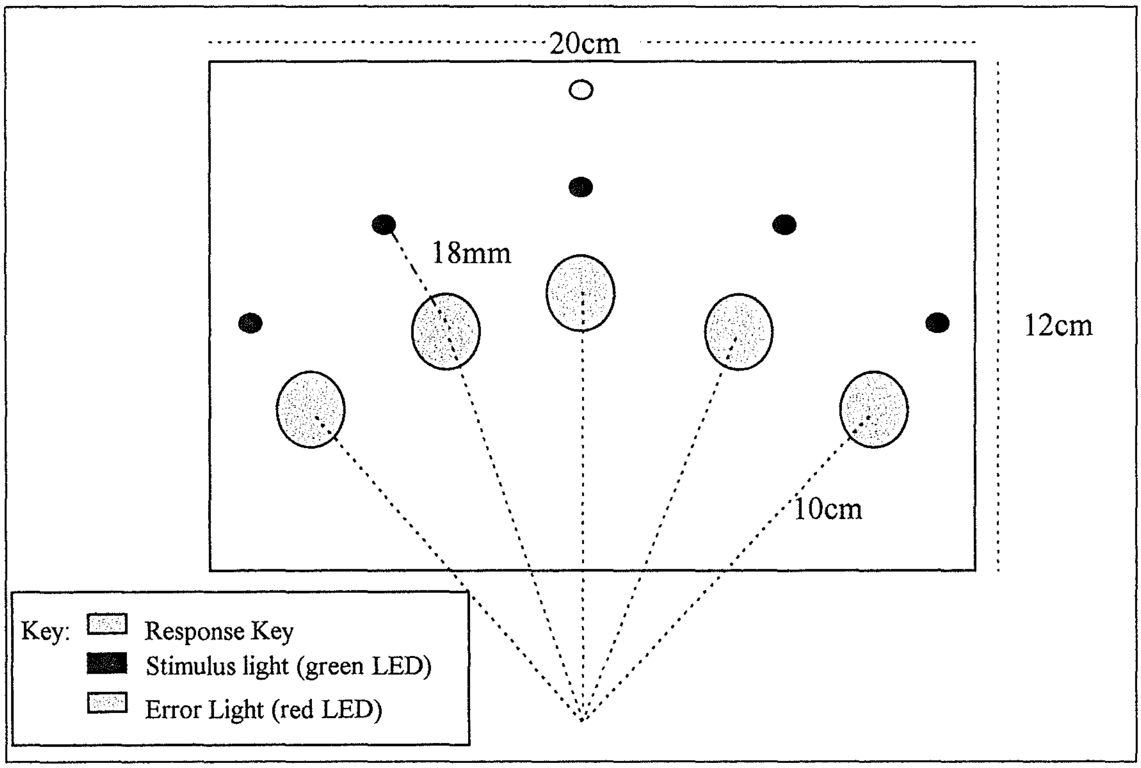
The dependent variables of interest were;

1) decision time in the serial reaction-time task (SRT),
2) replies to the verbal structured interview questions,
3) performance on the generate task,
4) performance on the recognition task.

2.3 Stimuli and Apparatus

The five stimulus lights (green LEDs) and corresponding response keys were mounted in an arc on a 20 x 12 x 4 cm response box (See Figure 2.30). Each response key consisted of a low pressure micro switch operated by the depression of a rod with the (diameter 2cm) button mounted on top.

Figure 2.30: Diagram illustrating the basic layout of the stimulus-response board used in this experiment.



The centre of the arc was 3 cm out from the near edge of the response box and 10 cm from the centre of each key. A distance of 18 mm (centre to centre) separated a response key from its corresponding stimulus LED. A red LED located at the top centre of the response box illuminated when a response error was made, or a key pressed in anticipation of (rather than after) the onset of a stimulus LED.

The experiment was controlled and response latencies recorded by an Intel 386 personal computer.

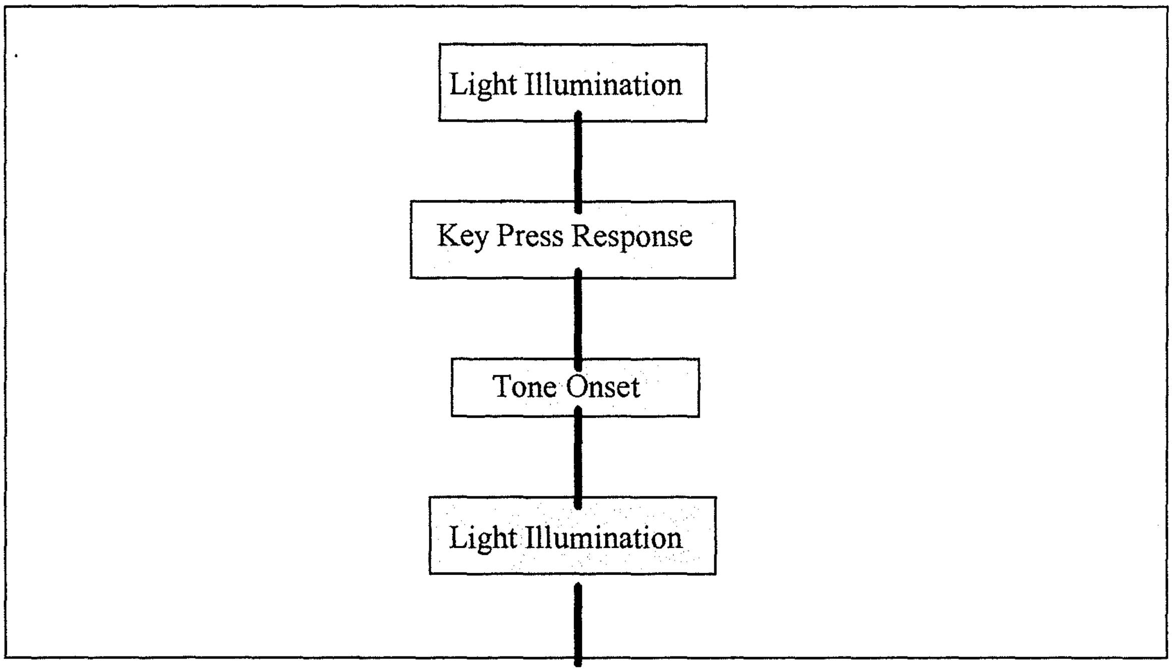
Participants completing the secondary task counted the number of higher tones in a random sequence of 450 Hz and 1250 Hz square wave tones. These tones were 60 msec in duration, with a tone sounding after each response had been made.

2.4 Procedure

The Serial Reaction-Time Task:

The sequence of events for each SRT trial is depicted in Figure 2.40.

Figure 2.40: The order of events in the serial reaction-time task (SRT) process.



First one of the five LEDs was illuminated. This was extinguished by depression of the appropriate response key. Next a tone was sounded for 60 msec and followed by a variable quiet interval of 110, 210, 310, 410, or 510 msecs prior to the onset of the next LED. The intervals were randomly determined and equiprobable for each trial. Variable intervals were included to discourage participants from commencing a response before the illumination of an LED on the subsequent trial.

Participants performed the experiment in a small, quiet room in the psychology department of the University of Canterbury. The computer monitor was placed in front of the experimenter, out of view of the participants who sat at a desk in front of the stimuli-response apparatus. Additionally, the experimenter and participants sat back to back to lessen participant anxiety and distractions.

Responses to the SRT were made with the index finger of the preferred hand, by depressing the appropriate key on the response board as each light illuminated. The instructions (Appendix B) given to the participants stressed that both speed and accuracy were equally crucial.

Half the participants were required to perform a secondary task concurrently with the SRT. This involved keeping a running total of the number of high-pitched tones experienced during each block. All participants were presented with a tone on every trial, but only those in the secondary task conditions were required to count them.

All participants completed a practice block of 40 trials, followed by the SRT training. Each of the eleven SRT blocks during the experiment consisted of sixty trials, with a predetermined series of lights. A small rest period was given between blocks.

The series of lights each participant experienced during SRT training depended on whether they belonged to the random control, structured control, or sequence group. Sequence group participants were trained with the sequence A-B-D-A-E-C-E-D-B-C-A-D, which was repeated five times in each 60 trial block. To remove any confounding of response time with key position, a separate random assignment of sequence letter code to light position was determined for each participant. In addition, starting each block at a different randomly determined position in the sequence undermined development of endpoint saliency.

For both control groups the spatial positions were also randomly allocated to the theoretical alphabetical position. The structured control group participants were presented with blocks of sixty trials drawn from a 130 trial sequence which matched the previously described twelve-long repeated sequence in relative frequency information. That is, the relative probabilities of any given movement between two key-positions were the same for both the sequence and for the structured control series. Again the starting point of the sequence was randomly determined for each block.

The participants in the random group received a predetermined random series of trials, except that no consecutive response repetitions were included in the series.

Participants completing the tone counting secondary task verbally reported the number of higher pitched tones counted to the experimenter at the completion of each block.

Problems were identified with the use of the traditional random practice block in this experiment. It was anticipated that a random practice block could advantage the random group participants during the following eleven SRT blocks. Even a random practice series incorporates certain relative frequency information that could be beneficial to the random control individuals in the ensuing SRT. To ensure that the sequence and frequency information changed for all participants from practice to SRT training, a second sequence was formed from which a series incorporating the sequence's relative frequencies was constructed. This series was used for participants of all training conditions in the practice block because it enabled them to practice the components of the SRT without acquiring any information relevant to the particular series they were to experience during SRT training.

Those participants who were randomly chosen to perform the secondary task in the SRT also practised this ability concurrently in the practice block.

All participants were encouraged, motivated and reassured using similar comments throughout the experiment, thus minimising the effect of experimenter feedback on reaction times. To further prevent experimenter effects, response times did not appear on the computer screen, and therefore were not available to the experimenter or the participant at any time during the experiment. Feedback with regard to performance accuracy on the SRT occurred through the use of a sixth LED (coloured red) which lit up when a participant responded prematurely (when the participant responds prior to light onset, or within 50 ms of the light illuminating). Additionally, if the participant responded incorrectly, the light remained illuminated until the correct response was made and the total response time was recorded along with the information that an error had occurred.

Structured Interview:

On completion of the SRT participants were asked a series of questions about the task (adapted from Reed and Johnson 1994, & Leadley 1997). These questions were designed to assess their explicit verbal knowledge of the information inherent in the series of lights they had experienced. These questions became successively more precise, and were as follows:

1) Have you anything to report regarding the task?
2) Have you noticed anything special about the task or the material involved in the task?
3) Can you describe anything about the task that made it easier? (What about the key-pressing part?)
4) Were there any regularities you noticed about the key pressing part?
5) [*If yes to 4*] Can you describe this regularity?
6) Were any lights or movements of lights more frequent than others?
7) [*If yes to 6*] Which ones?

Generate Task:

Two of the four groups who trained with the repeating sequence, and all the participants from the two control groups, then attempted the generate task. This involved producing a 60-long sequence of lights that were as similar as possible to the series of lights experienced during training. Participants were not informed of the existence of a sequence, (see Appendix C for the instructions given to the participants). However, all participants were told that the onset of lights had not been completely random and that there was some plan to them. The existence of a sequence was not outlined as it was considered important to keep the instructions identical for all participants completing the generate task, including those who had not encountered the sequence. To ensure that the task provided a good measure of the participants' predictive knowledge, an explicit link was made in the instructions between the generation task and the participant's knowledge of the information inherent in the SRT. Participants were given two lights (a randomly selected component of the twelve-long sequence given to sequence groups) from which to begin their generation. After their 60-long series had been completed all five green LEDs flashed indicating task completion. As the participants depressed each key during the task the appropriate lights illuminated. Each participant in this condition performed the task twice (with different cues on both occasions). The computer recorded the participants' generated series of key-presses.

Recognition Task:

Participants in the remaining two sequence groups completed a recognition task. Again they were informed that information was embedded in the training task, (see Appendix D for task instructions). Participants were presented with two blocks each consisting of 24 four-light segments to which they responded as in the training phase of the experiment. At the conclusion of each four-light segment the participants verbally indicated, according to a four-point scale, how familiar the sub-sequence seemed. The scale was comprised of the following ratings;

1=recalled encountering sub-sequence in training,

2=seems familiar,

3=seems unfamiliar,

4=did not encounter sub-sequence during training.

The four-light segments were either previously encountered sequence chunks or foils. The foils included only the transitions utilised within the sequence, but the participants had never previously encountered the particular combination of transitions making up the four-trial items during the eleven SRT blocks. Each of the two blocks consisted of the presentation of twelve sequence chunks and twelve foils. Familiarity ratings, (entered by the experimenter), were recorded by the computer.

On completion of these direct tests, all participants were debriefed as to the existence of the sequence and the aim of the experiment, and given their chocolate fish, can of coke and lottery ticket. (See Appendix E for an outline of the debriefing details).

3.0 RESULTS

3.1 Errors

'Incorrect key', anticipation, and secondary task errors were assessed.

Over the entire experiment, the probability of an incorrect key press was .02. The maximum error probability for any participant was .041.

When anticipation errors (DTs of less than 50 ms) were analysed with a 10% error allowance it was found that six participants reached or exceeded this limit. As five of the six belonged to the sequence group (four of these to the sequence, no secondary task, recognition test condition) and one to the structured control group it was thought that the occurrence of anticipation errors may reflect sequence knowledge. Initially, it appeared that anticipation errors did occur more frequently for some specific movements for each participant. However, on closer examination it was found that these movements bore no relation to information recalled or recognised in the direct tests of any of the five participants. It seems likely then that the uneven distribution of anticipation errors over conditions was a chance occurrence. The data for the six individuals in question was excluded from further analysis and six further participants were tested in their place.

Data from trials in which an incorrect key-press or anticipation occurred were pruned from the data for each participant, prior to analysis, unless otherwise stated.

Tone counting accuracy was assessed. Four participants failed to reach a 90% average-accuracy criterion, (within 10% either side of the correct answer). As these participants seemed to make an honest attempt to master the task they were not excluded from subsequent analysis. It was felt that the objective of the task had been met by these participants. Two of the participants in question belonged to the sequence + generate group (11.7%, 11.1% error rate), one to the sequence + recognition group (13.3%) and one to the structured control + generate condition (12%). By visual examination the results of these participants did not appear to differ from the remaining participants in their respective groups. A mixed training condition x block anova applied to the tone counting errors produced no significant main or interaction effects.

These results suggest that interpretation of DT and TRT data may proceed without complications from differential incorrect key press, anticipation or tone-counting errors.

3.2 Total Reaction Times

Median total reaction times (TRTs) for each of the eleven training blocks were obtained for every participant. The means of these medians are presented in ensuing figures and tables, unless indicated otherwise.

Data for the groups differing only in the direct tests of explicit knowledge completed after training were pooled. With the pooling of these sets of data, the following six conditions remained, refer to Table 3.20 below.

Table 3.20: Data from the eight experimental conditions were pooled to represent data from the following six groups for the purpose of DT and TRT analyses.

SEQUENCE GROUPS	STRUCTURED CONTROL GROUPS	RANDOM CONTROL GROUPS
Secondary Task	Secondary Task	Secondary Task
No Secondary Task	No Secondary Task	No Secondary Task

The expectation was that all groups would display a reduction in TRT across training blocks, with the rate of reduction being greater for the sequence and structured control compared to the random control group. However, TRT is confounded with distance between the consecutive keys pressed. That is, TRT also reflects the distance covered between keys, and whilst on average this distance is equated for the structured control and sequence conditions, it may not be for the random control conditions. Although this confound may result in longer or shorter TRTs for the random condition, it was hoped that the TRTs for the sequence and/or structured control group would illustrate a more rapid decline in TRT, possibly indicating learning of sequence or frequency information for these groups.

A training condition (sequence vs. structured control vs. random control) x secondary task (count vs. no tone count) x block anova was performed on the TRTs. This failed to produce evidence of differential effects of training condition on TRT across blocks, (see Figure 3.20). No interaction effects involving the conjunction of type of training with blocks approached significance. However, there were reliable secondary task $F(1,74) = 89.48$, $p<.001$, block $F(10,740) = 20.61$, $p<.001$ and secondary task x block $F(10,740) = 13.53$, $p<.001$ effects. These results reflect slower TRTs, and a greater rate of decrease in TRT across blocks when participants had to count tones, (see Table 3.21 and Figure 3.21).

No differences were found in the results when data corresponding to anticipation errors were included in the analysis.

Figure 3.20: The progression of TRT during the experiment for the three training groups.

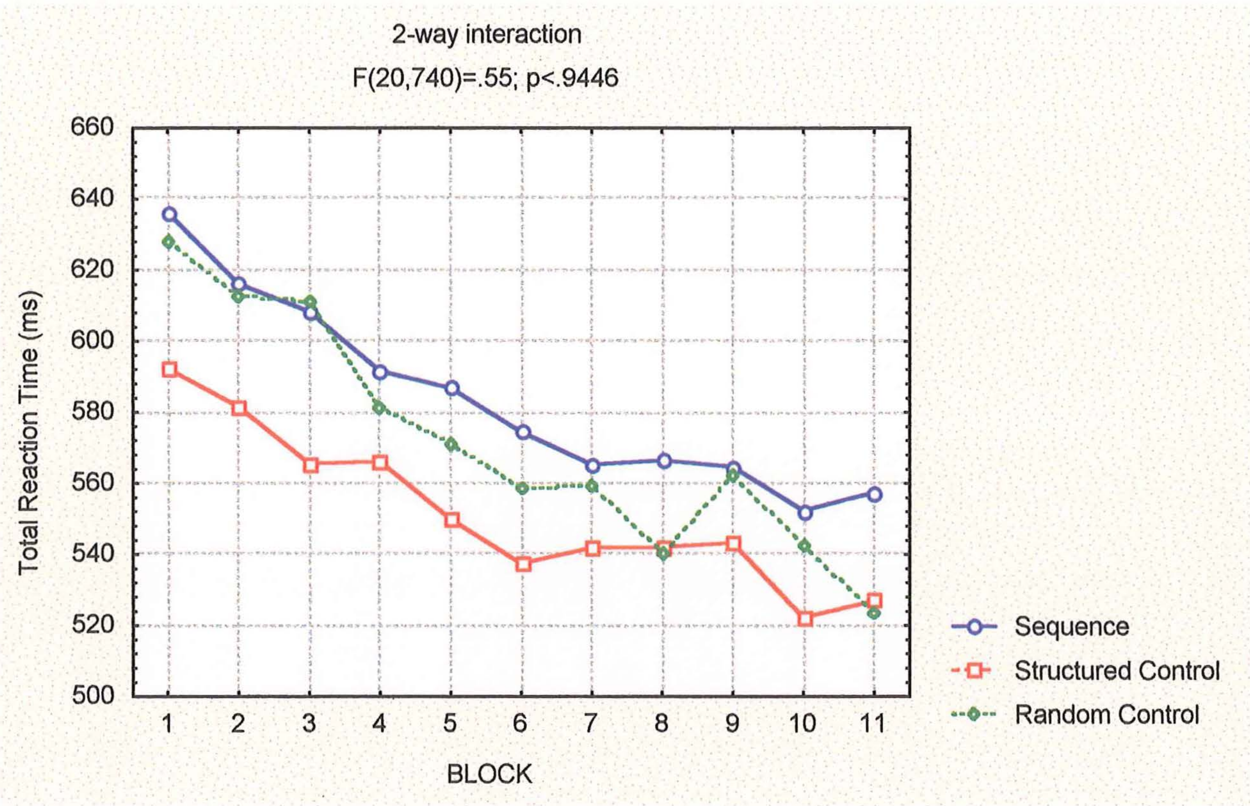
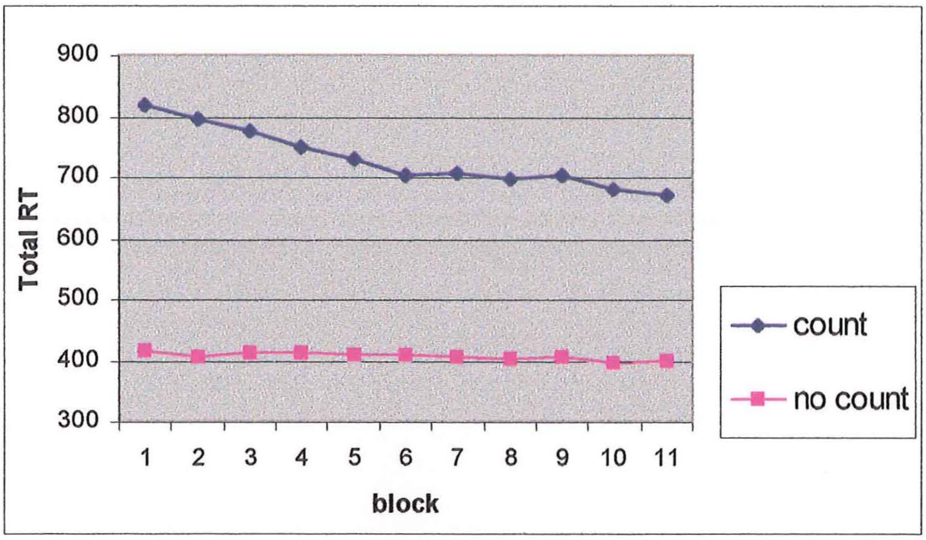


Table 3.21: Mean TRTs and standard deviations for each of the eleven blocks for each secondary task group.

	BLOCK										
	1	2	3	4	5	6	7	8	9	10	11
COUNT											
mean	828.23	805.51	783.38	754.44	738.20	713.43	711.05	701.60	710.36	687.43	682.41
standard dev.	248.11	238.01	218.77	199.18	199.12	198.95	204.07	169.52	203.88	191.27	183.2
NO COUNT											
mean	417.71	407.55	412.96	410.68	408.60	408.80	404.39	405.95	406.78	396.89	399.89
standard dev.	57.27	54.12	68.04	74.38	63.19	62.49	63.52	60.61	63.33	56.89	65.45

Figure 3.21: Mean TRT per training block for each secondary task group.



Since it is possible that averaging TRTs over an entire block of 60 trials may mask rapid learning of the information within the first block, a detailed analysis of this block was undertaken. The block was divided into five sub-blocks of 12 trials for each participant. For the sequence participant this referred to one sequence presentation. A training condition x secondary task x sub-blocks anova was performed. There was no evidence to suggest faster learning during the first block by any training group. Interactions involving the conjunction of training condition and sub-blocks failed to approach significance.

The effect of secondary task on TRT was also examined. There is an approximately 400 msec difference in TRT for count and no-count conditions, apparent from block one (see figure 3.21). This difference warrants further consideration. The secondary task may simply slow participants because it is still being completed, or by occupying working memory, (Jonides, 1995). Alternatively, it is possible that participants in the no-count conditions learned the task elements common in all training conditions very rapidly within the first block. Results from the previously mentioned training condition x secondary task x sub-blocks anova failed to provide evidence of faster block 1 learning by no-count participants. The secondary task x sub-block effect did not approach significance. The count no-count difference was not due to rapid learning by no-count participants. This suggests that the secondary task acts simply to slow participants, with the added task of counting occurring before or concurrently with the next trial.

From examination of figure 3.21 it might be concluded that decreases in TRT with training occurred only in participants also required to count the tones. In fact, simple main effects reveal that the decreases in TRT across training blocks is statistically reliable for both count and no-count groups: $F_{count}(10,370) = 19.23$, $p<.001$, $F_{no\text{-}count}(10,370) = 2.26$, $p<.05$). The difference in the rate at which TRT decreases for the two different secondary task conditions may simply reflect the continual learning, by the count participants necessary to accommodate the dual requirements of the tone counting and key-pressing.

3.3 Decision Times

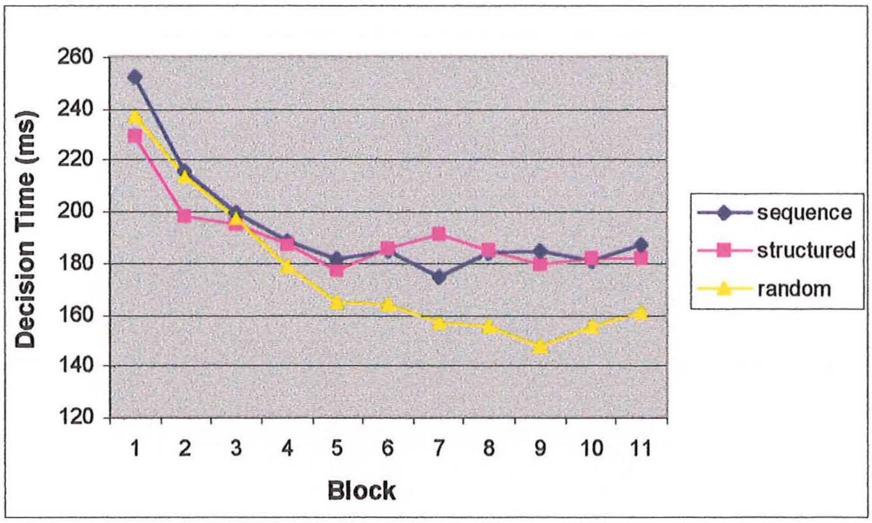
Median decision times were calculated for each of the eleven SRT blocks for each participant. These medians formed the data points for further analyses. For the purpose of the graphical comparisons, the medians for the participants in each training x secondary task group were averaged for each of the eleven blocks, unless stated otherwise. As for TRT, the DT data for the groups differing only in the direct tests after training, were pooled to give the six conditions listed in Table 3.20 (page 33).

DT is a measure of stimulus detection and response choice. The assumption in this experiment (from Leadley, 1997) is that response choice is explicit and deliberate. Therefore, when participants have explicit sequence or frequency information, this knowledge should be reflected in reduced DTs. It is expected that the sequence participants should illustrate a more rapid reduction in DT than the random control group. For the structured control group, the rate of decline in DT relative to the two remaining groups, bears on the question of whether frequency information is learned explicitly or implicitly. If this knowledge is implicit then no difference is expected in DT patterns between the structured control and random training conditions.

Figure 3.30 presents the DT patterns for the three training conditions. A training condition x secondary task x blocks anova revealed a significant blocks effect $F(10,740) = 20.94$, $p<.001$. However, no training group effect, or training group x blocks effect was found. An analysis including anticipation error data yielded identical results. Thus, contrary to expectation, there is no evidence for differential training effects over blocks.

As noted, it was expected that a greater rate of decrease in DTs would be found in one or both of the sequence and structured control groups, indicating the possibility of explicit knowledge. This prediction does not appear to be borne out by the data. As a further test of the hypothesis, the frequency of anticipation errors and the amount of anticipation (DT of 0-50ms) was analysed for the three training groups. Again it was thought that explicit knowledge might be indicated by a greater number of anticipation errors, or smaller decision times for the anticipations. However, in agreement with the DT finding, the three training groups did not differ in the number or degree of anticipations performed.

Figure 3.30: Mean decision time per training block for each training group.



As for the TRT data, the DT data from the first block was broken into five sub-blocks. No training group difference (as evidenced by the training group main effect and interaction with sub-blocks) was apparent.

The effect of secondary task on decision time data over the duration of the training is plotted in Figure 3.31 below. The training conditions x secondary task x blocks anova revealed a significant secondary task effect $F(1,74) = 8.13$, $p<.05$. DTs were greater for the participants who were required to count tones. Additionally, a significant interaction effect between block and secondary task was revealed, $F(10,740) = 2.78$, $p<.05$, most probably reflecting a slightly more rapid decrease in DT with training for the secondary task group. Table 3.30 presents the mean DTs and standard deviations for the eleven blocks as a function of secondary task.

A reduction in DT over blocks occurs for both the count ($F(10,370) = 11.91$, $p<.001$) and the no-count participants ($F(10,370) = 11.70$, $p<.001$), although the effect may be somewhat larger for the count group (as evidenced by the previously noted secondary task x block interaction effect). From Figure 3.31, the reduction in DT is most apparent during the first five blocks (300 trials).

Figure 3.31:Mean decision time per training block for each secondary task group.

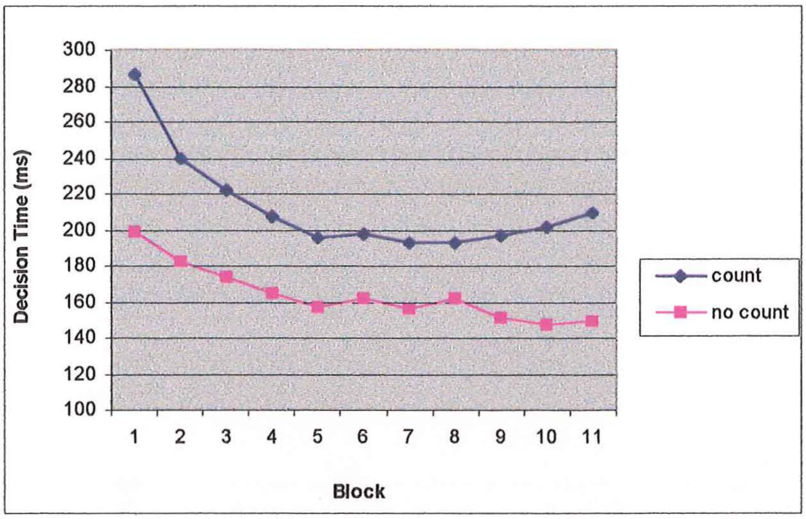


Table 3.30: Mean DTs and standard deviations for each training block for the count and no count groups.

	BLOCK										
	1	2	3	4	5	6	7	8	9	10	11
COUNT											
mean	305.6	251.13	232.68	219.73	208.7	211.5	198.63	208.5	220.98	218.75	228.23
standard dev.	154.97	94.15	81.03	90.5	101.14	97.55	92.15	95.18	102.89	102.34	125.02
NO COUNT											
mean	195.7	176.1	162.93	154.4	149.43	153.65	147.35	156.65	148.85	138.85	143.5
standard dev.	58.64	50.61	42.65	50.53	50.25	43.02	38.89	48.05	35.56	31.44	24.59

When the DT data from the first block was broken into five sub-blocks, the effect of the secondary task was examined. Specifically, evidence was sought for rapid learning in the no-count group which would account for the consistent difference between count and no-count groups over the eleven blocks. The anova did not reveal a significant secondary task x block effect, suggesting that the count and no-count groups have similar rates of decrease in DT within the first block. Thus, count participants showed slower DTs from the very beginning of the experiment, which are most likely due to the dual-task of SRT and tone counting.

The failure to find training group x block effects, coupled with a significant training effect across all training groups is problematic for Leadley's (1997) theory. Leadley would predict no decline in DT with training for the random control group. Additionally, (provided explicit knowledge is evidenced in either the sequence or structured control groups), Leadley would predict differential DT patterns over blocks for the training groups.

However, the divergence of these results from Leadley's predictions may reflect properties of the current version of the task. The very fact that training with a random series produced DT decreases with training may be interpreted as evidence for an impure measure of stimulus detection and 'decision time' in this experiment. There is the possibility that participants learned strategies that enabled them to release their finger from the key slightly earlier (without yielding an anticipation error). With the keys arranged in an arc (refer Figure 2.30 in method section) a plausible strategy might be to begin moving toward the centre of the arc, (either toward the centre key or just below it). The employment of such a strategy by all participants would result in decreasing DTs for all training groups, and would mask the expected differential DT patterns.

Examining the DTs for no-count groups (in Figure 3.31, or the random group in Figure 3.30), reveals DTs as short as 150ms. DTs this small may support the interpretation that participants are learning an anticipation strategy, despite the variable interval that was employed to discourage such anticipation. The sensitive switches used in the procedure (which did not require much pressure to hold down) may also be conducive to short decision times, but perhaps not to the extent of 150ms.

Another query surfaces when comparing the extent of the reductions in DT and TRT over training blocks, (refer Fig 3.31 and Fig 3.21). Count participants show average reductions in DT of 90ms, and reductions of 145ms in TRT. However, no-count participants decrease their decision times by 55 ms on average, whilst their TRT decrease is only 20ms over the training blocks. This implies that while decision time is decreasing with training for this group, the movement time from the release of one key to the depression of the next is actually increasing. One explanation for this counter-intuitive result is that the no-count participants, who are not loaded with dual task requirements, are more likely to take advantage of an anticipation strategy as outlined above. For these participants, DTs would decrease with use of a strategy such as moving toward the centre of the arc, but at the expense of movement time. Correcting movements mid-flight might be costly in terms of TRT, and swamp any benefits of instances where movement occurred in the direction that the light appeared.

3.4 Measures of Explicit Knowledge

Explicit tests were included for the following four reasons:

1) to determine if explicit knowledge is limited by the type of information available during training. If relative frequency information is learned explicitly, then both the structured control and sequence groups should exhibit greater explicit knowledge than the random control participants. However, if only higher order sequence information is amenable to explicit learning then the sequence participants alone should show evidence of explicit knowledge.
2) to assess whether the secondary task decreased the extent of explicit knowledge of frequency, fragment (including the entire sequence), and other knowledge relating to training. Traditionally, the rationale for including a secondary task in the SRT is to retard explicit learning of training information. Therefore, this line of analysis relates to whether the secondary task meets this objective.
3) to assess the effects on DT of explicit frequency and fragmentary sequence knowledge.
4) to determine the agreement between and validity of each of the various measures of explicit knowledge.

Potentially accurate explicit knowledge of the following is possible:

- Relative Frequency Information:

a) The simplest form of frequency information is the relative 1^{st}-order frequencies of various lights in a block of 60 trials. That is, whether some lights or keys occur more or less often than others, refer Table 3.40. During training, the sequence and structured groups did not differ in this level of information. The only information for the random group to learn is that all light locations are equiprobable.

Table 3.40: Relative 1st-order frequencies of the five stimulus lights in each block of 60 trials.

		Light				
		A	B	C	D	E
Training Group	Sequence	15	10	10	15	10
	Structured Control	15	10	10	15	10
	Random Control	12	12	12	12	12

b) Also classified as relative frequency information is knowledge of the subset of 2nd-order transitions which give rise to the movements actually used during training. With five light positions, and the requirement that no position repeat, there are 5 x 4 = 20 possible movements. In the random condition, each movement was equiprobable and occurred, on average, three times in each block of 60 trials. A subset of eleven movements was used in both the structured control and sequence conditions. Ten occurred five times in each 60-trial block, while the movement from D to A occurred 10 times in each block.

- Fragment/Sequence Knowledge:

The sequence group received five repetitions of a 12 long sequence (ABDAE-CEDBCAD) in each block of 60 trials. The sequence is comprised of 12 3rd-order fragments of the possible 80 presented to the random group, and 12 of the 320 possible 4th-order fragments.

The structured control participants received a series matching the above sequence in relative frequencies of positions and 2nd-order transitions. A greater variety of 3rd- and 4th-order fragments would have been encountered by participants in the structured control than sequence conditions. However, the range of these higher order fragments would not have been nearly as great as that in the random conditions because the full set of possible transitions was not used. That is, with only a subset of movements possible, the variety of larger fragments is limited.

Evidence of Explicit Knowledge from the Structured Interview:

Structured interview results for the training groups are summarised in Table 3.41 below. The numbers in parentheses are the number of participants in each group volunteering each class of explicit knowledge. The probabilities featured in the table refer to the probability that reported information was consistent with the actual fragment or relative frequency information derived from the 12-long sequence presented to the sequence group. The target sequence information were the eleven transitions possible in the sequence and structured control group training conditions, and the D and A light positions which occurred more frequently. If any participant reported one of the eleven transitions or one of the two lights (D or A) as occurring most frequently then this was regarded as target sequence information. Therefore, probabilities in Table 3.41 can be regarded as an indication of the hit rate (relative to the repeating sequence structure) proferred in the structured interview.

The probabilities reported here for the random control group reflect the ability to report this sequence information by chance alone. Comparing the performance of the other two training groups with the random group's chance performance gives an indication of which level of sequence information is acquired for each group.

At the fragment level of analysis, the fragments were broken down into simple transitions and the probability of these transitions being one of the subset of eleven possible is reported in the table. The rationale for this will be outlined in the following 'sequence information' section.

Table 3.41: Probability of reported information reflecting fragment or relative frequency information derived from the 12-long sequence presented to the sequence group. The numbers in parentheses refer to the number of participants volunteering information at each level.

	Transitions within Fragments	**Transitions Only**	**Individual Lights**
Sequence Group	.84 (14)	.75 (6)	.50 (9)
Structured Control Group	.91 (9)	1.00 (6)	.73 (7)
Random Control Group	.58 (2)	0.00 (0)	.36 (7)

Sequence Information:

➢ *Random Control Participants:*

The random control participants were presented with a series of lights in which all lights and movements of lights were equiprobable.

Two of the 20 participants stated that patterns did exist but kept changing. Between them, three 5-light series were given as examples. Of the twelve movements present in these chunks, seven (58%) were movements presented to the sequence and structured control participants, (refer to Table 3.41). Without examining random control performance, 55% accuracy would have been considered as reflecting chance. This is the probability of selecting one of the eleven sequence transitions of the twenty possible. The random control participants' performance gives some indication of the ability to give partially correct sequence components by chance alone.

➢ *Structured Control Participants:*

The structured control participants were not presented with a sequence they could learn, but did have particular lights and movements of lights which occurred more often.

No structured control participants reported that a pattern was evident during training. However, when asked if some movements occurred more than others, nine (of 20) reported chunks ranging from three to five movements in length. Because only a subset of the possible 2^{nd}-order movements could occur for these participants, the range of higher-order fragments encountered during training was limited compared to that presented to the random control participants. However, the range presented to the structured control participants, outside of the structure of a sequence, was greater than that received by the sequence group. Relative frequency alone can plausibly lead to statements regarding 3^{rd}-order (and higher) frequency information that are correct in the sense that they were encountered during training. The nine structured control participants collectively volunteered 13 3^{rd}-order (or greater) fragments. Only three of these fragments were not presented to the participant during training, (accuracy of

77%).

When the chunks that were reported were broken down into simple movements, the participants were 91% correct in their reported movement-components, compared to 58% for the random control group, (refer to Table 3.41).

Structured control participants appear to demonstrate explicit knowledge of fragments of the repeated sequence, to the level of that shown by sequence participants, although they were not presented with any repeating sequence during training. However, as already explained, knowledge of the relative frequency of transitions alone, in particular those transitions used versus those not encountered, can account for apparent segment knowledge.

➢ *Sequence Trained Participants:*

Four (all no-count participants) of the 40 participants within the sequence conditions reported definitely noticing a 'pattern'. None were able to reproduce the 12-item sequence used.

However, 14 participants (inclusive of the four above) reported knowledge of chunks (a series of three lights or more), even if they did not report belief in a complete sequence.

Of these 14:

- three gave only correct information
- four gave correct sequence fragments, along with incorrect ones
- seven gave only incorrect sequence chunks

The correct descriptions of fragments of the sequence all ranged from three to five lights in length. The incorrect chunks were usually either made up of movements which did occur, arranged into a higher order chunk which did not occur, or included one incorrect movement.

Therefore, it seems that the sequence participants do not produce reliable higher order fragment information. However, the chunks they do volunteer give evidence that they have learned some information about the sequence. If the chunks are broken down into simple movements then 84% of these reported movement components were sequence transitions (hence the information reported in table 3.41). This probability is considerably greater than the random control group's performance (58%), but is smaller than the corresponding structured control group probability of 91%. This latter comparison could be interpreted as evidence for explicit learning of the frequencies of the particular lights and movements within the sequence only. That is, the sequence participants may only have explicit knowledge of the 1st- and 2nd-order frequency information inherent in the sequence, and this may be sufficient to account for their reported higher order fragmentary sequence information.

Relative Frequency Information:

➢ *Random Control Participants:*

Eleven of the 20 random control participants correctly reported that no lights or transitions of lights were more frequent than others during training.

One reported that entire sweeps along all keys from one side to the other in either direction were rare, and was probably correct in this statement as a random series of lights should generate these sweeps infrequently.

♦ Particular Lights:

Seven of 20 participants reported that certain lights occurred more frequently during training. The light series were generated at random for these participants (with replacement, and the proviso that no consecutive lights were the same) so it could be assumed that all lights should occur equally often. However, due to the random selection of lights, it is possible that for any one participant particular lights may have occurred more frequently. Over eleven blocks of training this is very improbable. It is difficult to know for certain whether these participants are correct in their claims, but it is likely that they are not. Thirty six percent of the lights that these seven participants believed occurred more frequently were either the A or D light that did occur most often for the sequence and structured control group. This percentage reflects the ability to report these lights as more frequent by chance alone and is the basis for the .36 probability reported in Table 3.41.

♦ Transitions:

Table 3.41 illustrates that no random control participants volunteered transitions that they believed occurred more frequently than others (hence the 0(0) entry in Table 3.41).

From these results, it appears that participants who receive a random series of lights and transitions nevertheless generate some hypotheses about the structure of the series encountered during training.

➢ *Structured Control Participants:*

Fourteen of the 20 structured control participants could report knowledge of frequency information.

♦ Particular Lights:

Of these 14 participants, seven believed that one or more single lights occurred with greater frequency than the rest. While they were not always correct in naming D or A as the most frequently occurring lights, they were correct on 73% of the occasions that they named a more common light, (see Table 3.41).

Of the seven:

- six correctly picked that one or both of the lights D and A occurred more frequently.
- four incorrectly selected one or more of lights B, C, or E as occurring more frequently.

Two stated that one of the latter three lights occurred less frequently than the others. (It is difficult to know whether to judge these participants as correct or incorrect in this assumption as B, C and E occurred with equal probability, but did occur less than lights A and D).

♦ Transitions:

Six of the 14 participants offering frequency information gave particular transitions that they believed had occurred with some regularity.

Of these six:

- six (probability of 1.00 in Table 3.41) reported only sequence transitions that occurred during training.
- one reported the DA transition that occurred most frequently, and this transition featured six times within fragments of three lights or more produced by structured control participants.
- one incorrectly stated that if light A occurred there was a 50% probability of D following, (real probability of .33).

It can be concluded that at least some of the structured control participants demonstrate explicit knowledge of the relative light and transition frequency information inherent in the training series.

➢ *Sequence Trained Participants:*

Frequency information (relative frequency of lights or keys, and 2nd-order movements between keys), was supplied by 13 of the 40 participants within the sequence groups. Four also supplied sequence chunks.

♦ Particular Lights: Nine reported a greater frequency of one or more individual lights. (50% of the named lights did occur more often. Chance accuracy is 40% which reflects randomly choosing the correct two of the five lights).

♦ Transitions:

- Six claimed that some transitions occurred more regularly. One person was completely incorrect. The six participants drew 75% of the reported movements from the subset of actual transitions present during training, (refer to Table?).
- only 2 reported noticing the one movement (DA) that actually occurred the most often. However, this movement was reported as part of a 3rd-order (or longer)

chunk by four other sequence participants.

- 1 correctly reported that a particular movement never occurred.

Within the sequence, only some transitions were possible, all occurring once per sequence of twelve lights with the exception of one movement (DA) which did occur twice per sequence.

Seventeen of the 40 sequence-condition participants failed to report any knowledge of sequence existence or frequency information.

From the results of this and the previous section it maybe concluded that both structured control and sequence group participants appear to demonstrate explicit knowledge of the relative frequency of lights and movements, and of some fragments.

<u>Training Effects on Explicit Knowledge:</u>

Results from the structured interview support the following conclusions. First, some participants trained with a repeating sequence or structured control series give explicit reports of the relative frequency of lights and transitions. Thus, explicit knowledge is not confined to the reporting of an entire sequence or even fragments of a sequence. Further, this frequency information may be sufficient to account for the explicitly reported sequence fragments. One cannot be certain, from this direct test alone, that it is possible to explicitly report fragmentary sequence information.

One potential criticism of the structured interview is the possibility that information given by participants may not be genuine. The probability with which sequence movements are given for the three training groups indicates that the sequence and structured control participants are performing above chance levels when reporting training information. That is, the structured control and sequence participants are not simply guessing. This supports the conclusion that participants in the structured interview volunteer information they believe to be genuine.

Recognition Task:

The recognition test involved presenting 20 of the sequence group participants with fragments (four lights in length) which did or did not occur during training. The participants responded to the lights as in the SRT and then rated the fragment according to its familiarity. The rating scale ranged from 1 (recalled encountering during training) to 4 (did not encounter sub-sequence during training).

The recognition task is a test of fragmentary sequence knowledge only and cannot be used to classify participants according to relative frequency knowledge. This is because only movements that actually occurred during training were used in generating both the foil and the target fragments. Relative frequency information alone will not be beneficial to performance on this task. If only frequency information had been learned explicitly, then sequence participants should have difficulty differentiating between foils and fragments. If participants can distinguish previously encountered sequence fragments from totally new arrangements of the individual movements, target ratings should be statistically reliably lower.

It is also possible that fragment knowledge is in part at least supported by the knowledge that some component movements, DA in this case, occur more frequently. If this is so, differences in ratings containing and not containing the movement from D to A are to be expected. It was predicted that fragments containing the DA movement would be associated with a greater rating of 'recalled from training' than fragments which did not include the movement. Additionally, participants may be more aware of the movements which neighbour the DA transition. This would be reflected in a greater target-foil rating difference for fragments containing the DA movement.

Finally, as in previous investigations employing recognition tests (Leadley 1997, Reed & Johnson 1994, for example), the recognition test was administered twice to assess the fragility of explicit fragment knowledge.

To address these issues the recognition ratings for each participant were averaged to give mean ratings on each test occasion. Mean ratings were found for previously encountered fragments which included the movement from D to A (Target DA) and which did not include the DA component (Target non-DA), and for fragments which had not been previously encountered but which did or did not include the DA transition (Foil DA, Foil non-DA). Group mean ratings and their standard deviations are reported in Table 3.42.

Table 3.42: Mean and standard deviation of group recognition ratings.

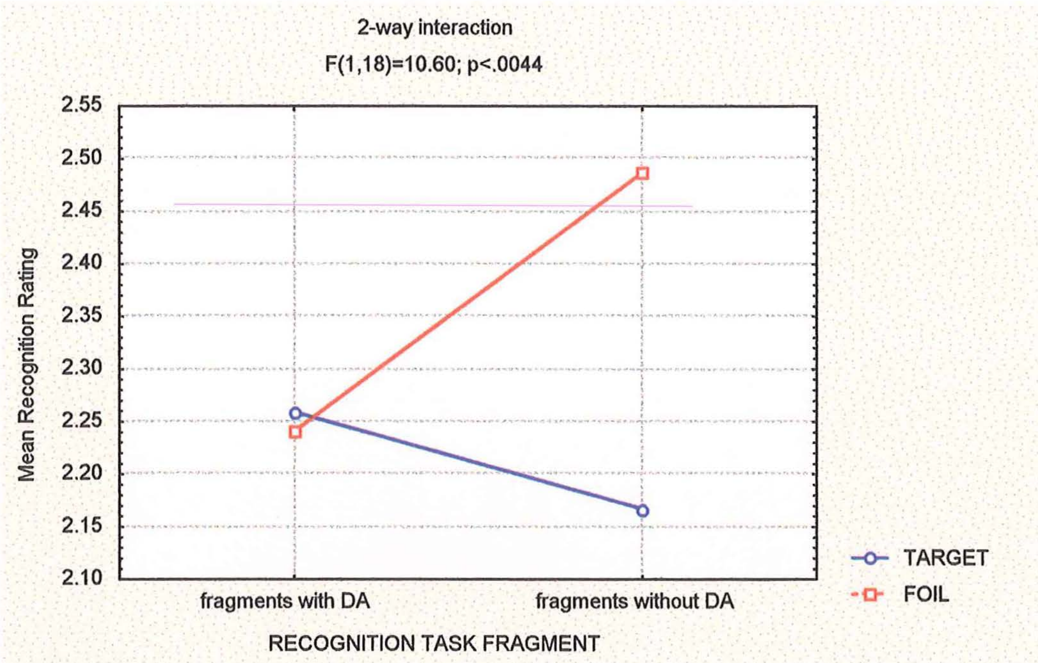
		Occasion 1			
		Target		Foil	
Secondary Task		DA	non-DA	DA	non-DA
No Count	Mean	2.08	2.13	2.14	2.54
	Standard Dev.	0.34	0.53	0.56	0.60
Count	Mean	2.30	2.20	2.28	2.50
	Standard Dev.	0.48	0.54	0.52	0.34

		Occasion 2			
		Target		Foil	
Secondary Task		DA	non-DA	DA	non-DA
No Count	Mean	2.18	2.03	2.12	2.29
	Standard Dev.	0.36	0.62	0.52	0.66
Count	Mean	2.47	2.3	2.42	2.61
	Standard Dev.	0.61	0.52	0.49	0.38

Participant mean ratings were treated by a secondary task x occasion x target versus foil x DA versus non-DA anova. The variable of greatest interest relates to the target versus foil difference. However, this main effect was not significant.

The predicted main effect of DA versus non-DA fragments on recognition ratings did not approach significance. However, an interaction effect between target versus foil and DA vs non-DA fragments reached significance, $F(1,18)=10.61$, $p<.01$. Figure 3.40 below illustrates this interaction. It was thought that greater target-foil differences would be evident for the fragments containing the DA transition. Figure 3.40 indicates, contrary to prediction, that the interaction reflected a greater foil-target difference for fragments not including the DA movement. Separate analyses for fragments with DA, and not including DA, reveal that the target-foil difference exists only for the fragments which did not incorporate the DA transition, $F(1,18)=12.4$, $p<.01$.

Figure 3.40: Mean recognition ratings of target and foil items containing and not containing the DA movement.



One possible explanation for this result is that participants have explicit knowledge of the DA movement, without knowledge of neighbouring movements and are therefore more likely to respond to any recognition item including DA (foil or target) by rating it as recognised.

This result indicates possible explicit knowledge of the DA transition which occurred more frequently during training. Moreover, the reliable target-foil difference for fragments not incorporating the DA movement indicates that participants do have explicit fragment knowledge. It appears that the explicit knowledge of the DA movement, which is associated with 'recognised' ratings for both foils and targets containing the transition, may mask the main effect of target versus foil ratings that were expected to indicate explicit sequence knowledge.

The recognition test was completed twice to assess whether measured awareness decreased over repetitions. The secondary task x occasion x target vs. foil x DA vs. non-DA anova did not reveal a significant effect of occasion on recognition ratings, or an interaction between occasion and the different types of fragments. This indicates that, as found by Reed and Johnson (1994) and Leadley (1997), performance for the two occasions was similar. Mean ratings for Occasion 1 target and foil fragments were 2.18 and 2.39 respectively. For Occasion 2 the corresponding mean ratings were 2.25 and 2.38.

The interaction between secondary task and occasion was significant $F(1,18)=6.96$, $p<.05$. This interaction is not related to the target-foil or DA-non-DA variables of interest here. This result will be discussed in a further section relating to the effects of the secondary task. The absence of further interactions involving the occasion variable leads to the conclusion that the effects of the secondary task and occasion variables are not a potential concern for the recognition task findings.

The recognition test, generally regarded as a more sensitive direct test than the structured interview, (Shanks & St. John 1994) performed with sequence participants, appears to reveal that fragmentary sequence knowledge is amenable to explicit learning. Additionally, it appears that knowledge of the more frequently occurring DA transition was evident in the recognition ratings.

Training Effects on Explicit Knowledge:

As the recognition test can only directly assess fragmentary knowledge and not relative frequency information, only partial conclusions regarding what training information is associated with explicit learning can be drawn. From this direct test alone, one could conclude that higher order sequence information is amenable to explicit learning and is evident amongst this group of participants.

Generate Task:

Results of the 60-trial generate task are displayed in Table 3.43 which follows. The letters in the second column comprise the sequence that the sequence group were presented with during training, and the table gives the frequencies with which participants from the three different groups (sequence/ structured control/ random control) produced subsections of the sequence. The result '9(4)' in the first row under the column labelled '4', translates to the production of nine 4^{th}-order sequences of ABDA by four participants from within the sequence groups. Likewise, '17(10)' from the sixth set of rows in the column labelled '3' refers to the generation of 17 3^{rd}-order CED sub-sequences by 10 participants within the structured control groups. In the columns labelled '1', '2' or '3' an asterisk beside the entries denotes a statistically significant result obtained from an anova comparing the frequency with which the fragment is produced between the differing training groups.

The rationale underlying the generate task in this experiment is as follows. If participants in either the sequence or structured control groups (or both) possess explicit knowledge of the sequence or the frequencies involved during training, they should produce more of the sequence components than the random group. The participants constituting the random conditions should be generating these sub-sequences by chance alone. At this level, it is of little interest which particular components of the sequence are generated more frequently by the structured control or sequence groups, (although this information is useful when analysing the effect of explicit knowledge on DT). What is central is whether fragments, in general, are produced more frequently by either of these two groups. The particular high-order fragments recalled and generated by the participants within each group may well differ.

Table 3.43: Frequency of the generation of sequence fragments. The figures in parentheses indicate the number of participants generating each fragment on one or more occasions.

			Fragment Length								
Serial Position	**Spatial Position**	**Group**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	A	**Seq**	246(20)	52(18)	24(12)	9(4)	1(1)	1(1)	0(0)		
		Struct	280(20)	54(18)	17(12)	6(6)	1(1)	0(0)			
		Random	255(20)	60(17)	20(11)	3(3)	0(0)				
2	B	**Seq**	250(20)	72(19)	36(15)	10(7)	5(4)	3(3)	1(1)	1(1)	0(0)
		Struct	209(20)	73(18)	32(15)	10(7)	4(4)	0(0)			
		Random	243(20)	65(19)	18(11)	7(5)	1(1)	0(0)			
3	D	**Seq**	246(20)	76(19)*	24(13)	10(8)	4(4)	1(1)	1(1)	0(0)	
		Struct	289(20)	123(19)*	36(15)	17(10)	1(1)	1(1)	1(1)	0(0)	
		Random	256(20)	69(17)*	16(10)	3(3)	0(0)				
4	A	**Seq**	246(20)	59(17)	23(12)*	8(6)	2(1)	2(1)	0(0)		
		Struct	280(20)	80(17)	35(12)*	4(3)	3(3)	2(2)	0(0)		
		Random	255(20)	61(17)	11(10)*	2(2)	1(1)	0(0)			
5	E	**Seq**	248(20)	84(19)	21(12)	8(5)	4(3)	0(0)			
		Struct	223(20)	82(17)	11(8)	6(6)	3(3)	0(0)			
		Random	239(20)	57(18)	9(5)	5(4)	0(0)				
6	C	**Seq**	250(20)	89(18)	26(13)	8(6)	1(1)	1(1)	0(0)		
		Struct	239(20)	71(18)	17(10)	7(6)	0(0)				
		Random	247(20)	60(18)	15(12)	3(3)	2(2)	1(1)	0(0)		
7	E	**Seq**	248(20)	56(18)	16(11)	2(1)	2(1)	0(0)			
		Struct	223(20)	79(16)	25(11)	9(5)	3(3)	1(1)	0(0)		
		Random	239(20)	64(18)	17(8)	6(4)	3(3)	0(0)			
8	D	**Seq**	246(20)	68(17)	23(11)	8(3)	3(3)	0(0)			
		Struct	289(20)	76(19)	21(10)	9(6)	2(2)	1(1)	1(1)	0(0)	
		Random	256(20)	67(19)	13(7)	4(3)	0(0)				
9	B	**Seq**	250(20)	59(16)	15(7)	7(6)	0(0)				
		Struct	209(20)	55(18)	16(11)	4(4)	1(1)	1(1)	0(0)		
		Random	243(20)	53(17)	12(9)	1(1)	0(0)				
10	C	**Seq**	250(20)	57(17)	20(13)	3(3)	3(3)	0(0)			
		Struct	239(20)	74(18)	14(10)	4(3)	2(2)	0(0)			
		Random	247(20)	53(19)	11(8)	3(1)	0(0)				
11	A	**Seq**	246(20)	69(19)	14(12)*	5(5)	2(2)	0(0)			
		Struct	280(20)	89(19)	42(13)*	9(5)	2(2)	0(0)			
		Random	255(20)	56(19)	15(8)*	1(1)	1(1)	0(0)			
12	D	**Seq**	246(20)	76(19)	18(13)	6(6)	0(0)				
		Struct	289(20)	123(19)	21(11)	7(5)	2(2)	1(1)	0(0)		
		Random	256(20)	69(17)	13(9)	3(3)	1(1)	0(0)			

To test the prediction that explicit knowledge will result in sequence or structured control participants generating more sequence fragments than random control participants, the data in the table were collapsed for analysis over examples from within each order (2^{nd}-, 3^{rd}- and 4^{th}-order and so on). This resulted in the mean number of fragments produced by each participant for each order of generation. These data were entered into a training groups x secondary task anova. The analysis is redundant at the 1st-order level of generation, as all participants will produce a total of 60 1^{st}-order key-presses.

Additionally, relative frequency information may impact on which movements and fragments are generated. It is assumed that explicit frequency knowledge will lead to the more frequently occurring (during training) lights and movements being generated more often. From such an analysis, it should be possible to ascertain which training types result in explicit relative frequency knowledge.

<u>Relative Frequency Information:</u>

- 1^{st}-Order Information:

This refers to the number of times each participant generated each key in the 62-trial long generation sequence. Group mean key-press frequencies are presented in table 3.44 and figure 3.41 below. The expectation is that the mean number of times each location is generated should be approximately equal for the random control group participants, but reflect the greater frequency of D and A (which occurred 1.5 times more frequently than B, C and E during training) for the structured control and sequence group.

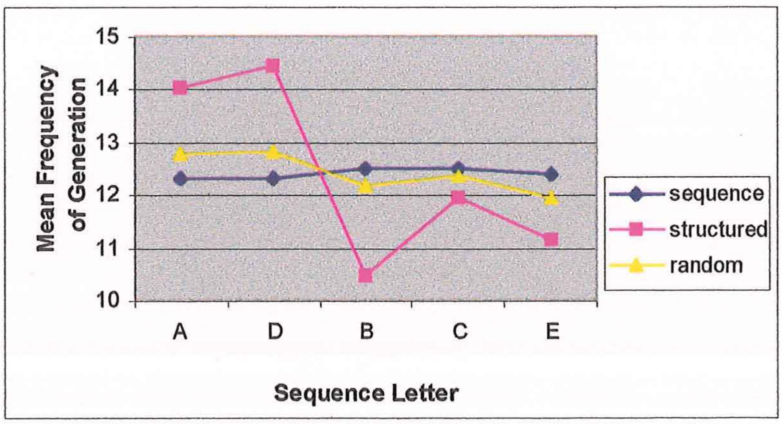
To test this prediction a training group x secondary task x position anova was conducted. This analysis contrasted the pooled frequency with which the 'A' and 'D' positions were generated, with the less frequent pooled 'B', 'C', and 'E' positions. The results pertaining to the main effects of training group and position frequency were significant $F_{group}(2,54)=3.94$, $p<.05$, and $F_{position}(1,54)=5.76$, $p<.05$. The interaction between these two variables was also significant, $F(2,54)=3.94$, $p<.05$. These significant results appear to be due to the reflection of the training frequencies in the generation performance by the structured control participants. That is, those in the structured control condition produced the positions 'A' and 'D' more frequently during the generation task than the remaining three possibilities. Separate contrasts on the data for the three training groups indicate that only the structured control group demonstrated an A, D versus B, C, E difference, $F(1,19)= 10.94$ $p<.01$.

These results indicate that the structured control, but not the sequence-trained participants, are able to explicitly report information regarding the relative frequencies of the various lights in the generate task.

Table 3.44: Training group mean key-press frequencies and standard deviations for the five locations.

		Position				
		A	B	C	D	E
Sequence	Mean	12.30	12.50	12.50	12.30	12.40
	Standard Dev	2.94	3.12	3.73	2.79	3.12
Structured Control	Mean	14.00	10.45	11.95	14.45	11.15
	Standard Dev	3.60	2.46	2.82	3.09	3.53
Random Control	Mean	12.75	12.15	12.35	12.80	11.95
	Standard Dev	3.53	3.35	3.32	3.02	3.39

Figure 3.41: Mean frequency of generation of each position for the three training groups in the generate task.



- 2^{nd}-Order Information:

One indication of explicit 2^{nd}-order knowledge on the part of participants in the sequence or structured control groups would be the generation of a greater number of 2^{nd}-order fragments relevant to the sequence (hereafter referred to as target fragments) than produced by participants within the random control group. A training groups x secondary task anova was performed on the number of 2^{nd}-order target movements produced by each participant. This analysis revealed that the three training groups did not generate a different number of 2^{nd}-order target fragments. However, the failure to detect a training groups difference at this level of analysis does not necessarily indicate that the participants of the sequence and structured control groups do not have any knowledge of the 2^{nd}-order frequency information embedded within their training series.

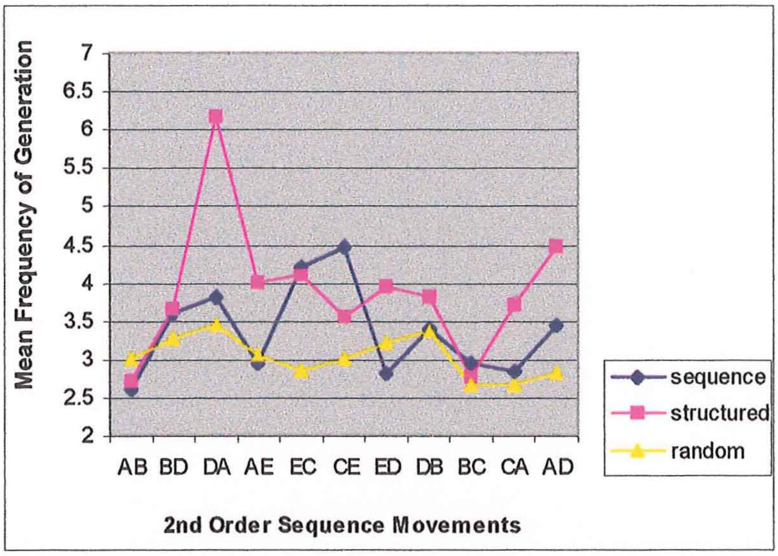
When the uneven distribution of the 2^{nd}-order fragments during training for the sequence and structured control participants is considered, a closer examination of the data may be informative. During training the movement 'DA' occurred with double the frequency of the other ten possible sequence movements for the sequence and structured control groups. Again the random group were exposed to all possible movements with equal probabilities. Table 3.45 below presents the mean generation frequencies (and standard deviations) of the eleven transitions for each training group. Figure 3.42 suggests that the structured control group produced 'DA' more frequently than the other eleven target movements, whilst the sequence group showed no sensitivity to this frequency information during the generation task.

Table 3.45: Training group mean generation frequencies and standard deviations for the eleven transitions.

		Transition										
		AB	BD	DA	AE	EC	CE	ED	DB	BC	CA	AD
sequence	mean	2.60	3.60	3.80	2.95	4.20	4.45	2.80	3.40	2.95	2.85	3.45
	st'd dev	2.87	2.37	2.02	1.76	2.21	2.89	1.77	2.44	2.52	2.32	2.35
structured	mean	2.70	3.65	6.15	4.00	4.10	3.55	3.95	3.80	2.75	3.70	4.45
	st'd dev	1.92	2.28	3.69	3.43	3.74	3.30	3.86	3.22	2.20	4.18	2.68
random	mean	3.00	3.25	3.45	3.05	2.85	3.00	3.20	3.35	2.65	2.65	2.80
	st'd dev	2.55	2.02	2.48	2.63	2.03	2.53	1.88	2.39	2.39	2.03	1.77

Accordingly, an anova involving training groups, secondary task, and contrasting DA with all other movements was performed on the number of times each movement was generated. The main effects of training group and frequency of presentation during training, and the interaction between the two, reached statistical significance, $F_{group}(2,54)=5.75$, $p<.01$, $F_{DA\text{-}movement}(2,54)=9.73$, $p<.01$, $F_{gpxDA\text{-}movement}(2,54)=3.35$, $p<.05$.

Figure 3.42: Mean frequency of generation of particular movements for the three training groups.



When an analysis of only the data pertaining to the DA transition was undertaken, a training group x secondary task anova revealed a significant training groups effect for the generation of the DA transition, $F(2,57) = 5.43$, $p<.01$, (Refer to table 3.43 which displays asterisks for this finding). No such effect was found when this analysis was performed on the generation data for the remaining ten transitions. Figure 3.42 suggests that the DA movement was produced significantly more often in the generation task by participants within the structured control group, than those in the two remaining groups. Individual post hoc contrasts of the DA generation for the structured control group with the two remaining training groups indicate that the structured control participants differed significantly in their DA generation from the random group (Tukey's HSD test $p<.05$), and from the sequence group (Tukey's HSD test $p<.05$). No difference is evident between the sequence and random control groups.

In summary, no training group difference in the number of 2^{nd}-order fragments generated was found. However, when the analysis was focused on the relative frequencies of the 2^{nd}-order transitions in training, a difference between the sequence and structured control groups was evident. The structured control, but not sequence participants, demonstrated explicit knowledge of the more frequent DA movement in their generation performance.

Sequence Information:

- 3^{rd}-Order Fragments:

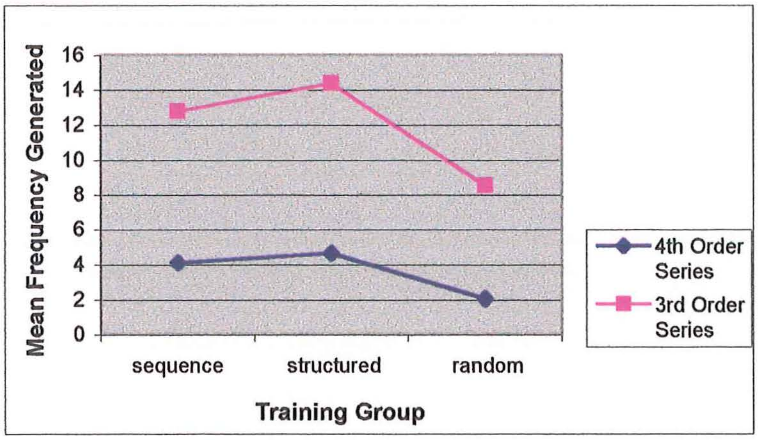
Mean generation frequencies (and standard deviations) for 3^{rd}- and 4^{th}-order fragments are presented in table 3.46 below.

As for the 2^{nd}-order level of analysis, an anova was conducted to assess training group differences in the number of 3^{rd}-order fragments generated. The training groups x secondary task anova revealed a significant difference in the frequencies with which the sequences of length three were generated by the three training groups, $F(2,54) = 9.03$, $p<.001$. Refer to Figure 3.43 below which illustrates that this result is due to both the sequence and structured control group producing more 3^{rd}-order sequences than the participants from the random control group. Post hoc analyses indicate differences between the sequence and random groups (HSD test $p<.01$), between structured control and random groups (HSD test $p<.001$), but not between sequence and structured control groups. This training group difference indicates explicit knowledge of sequence fragments of length three by the sequence participants, and by the structured control participants, whom it should be remembered, did not receive these fragments repeatedly in a sequence during training.

Table 3.46: Mean training group frequencies and standard deviations for the total generation of 3^{rd}- and 4^{th}- order fragments.

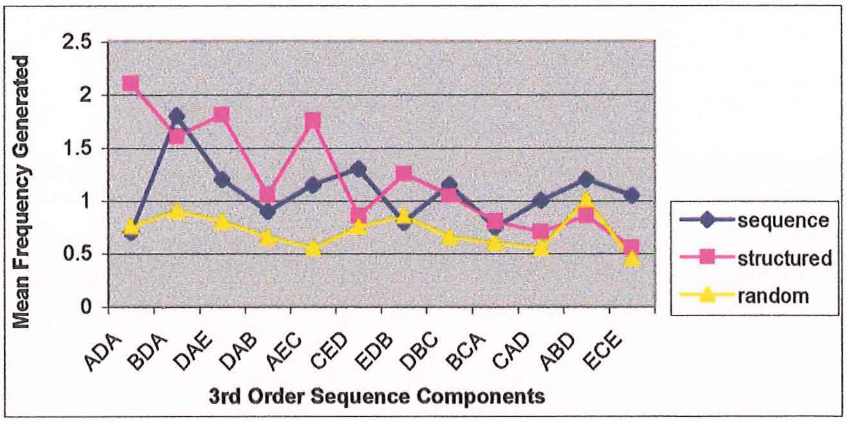
		Fragments	
		3rd-order	4th-order
Sequence	Mean	12.75	4.2
	Standard Dev	6.13	3.86
Structured Control	Mean	14.35	4.65
	Standard Dev	3.6	1.98
Random Control	Mean	8.5	2.05
	Standard Dev	3.24	1.57

Figure 3.43: Mean number of times participants from each training group generated 3rd- and 4th-order sequence fragments.



The twelve 3rd-order fragments were presented equally often in sequence training. Nevertheless, it is possible that fragments containing the more common DA movement would be generated more frequently. To assess this an anova featuring training groups, secondary task, and the twelve 3rd-order fragments used in training was undertaken. This revealed a significant training group main effect, $F(2,54)=9.61$, $p<.001$. Differential generation within the twelve fragments was also indicated, $F(11,594)=2.26$, $p<.05$, (see Figure 3.44)

Figure 3.44: Mean frequency of generation of 3rd-order fragments as a function of training group.



Six asterisks are featured within Table 3.43 for the 3rd-order fragments AEC and ADA, indicating that the three training groups differed in the number of times they generated these particular fragments, $F_{AEC}(2,57) = 3.76$, $p<.05$, and $F_{ADA}(2,57) = 4.74$, $p<.05$. There were no other reliable differences between training groups in the frequency of generation of 3rd-order fragments. The AEC fragment was generated more often by both the sequence and structured groups than the random control group, (sequence versus random control HSD post hoc test $p<.05$, and structured versus random control HSD test $p<.05$). However, the structured group generated the ADA fragment more often than both the sequence and random control groups, (structured vs. sequence HSD test $p<.05$, structured vs. random control HSD test $p<.05$) . Refer to Figure 3.44 above for illustrations of these findings.

Frequency information with regard to light reversals (ECE and ADA in this study) is considered as salient information which may have a higher likelihood of association with explicit knowledge, (Reed & Johnson, 1994). The structured control group generated the ADA fragment with greater frequency than the remaining two training groups. However, knowledge of this fragment is likely to be the result of the knowledge of the more frequent DA transition, than a function of the reversal. This is evident as the ECE reversal fragment does not appear to be associated with explicit knowledge. No evidence of explicit knowledge of 3rd-order target reversals is apparent from the data.

- 4th-Order Fragments:

The frequencies with which the particular fragments of length four (or greater) were generated were too small to safely conduct an anova for each individual movement. Since insufficient fragments were generated for the individual fragment analysis, the total number of 4th-order fragments generated by each participant were examined.

Figure 3.43 features the frequency with which 4th-order sequence fragments were generated by the three training groups. The training groups x secondary task anova produced a significant training groups effect, $F(2,54) = 5.75$, $p<.01$. Again, sequence and structured control participants produced significantly more fragments (refer to figure 3.43) than the random control group (sequence vs random HSD test $p<.05$, structured vs. random HSD test $p<.001$), indicating that both the structured control and sequence groups demonstrated explicit knowledge of 4th-order segments. This is problematic in the case of structured control who received a greater range of 4th-order combinations during training than the sequence participants. Structured control participants appear to distinguish between the fragments they were presented with and those that were not possible from the subset of actual transitions. This ability would lead to facilitated generation at the 4th-order level.

- 5th-Order Fragments:

Due to the low frequencies of 5th-order fragment generation, an anova could not be safely conducted without violation of the assumption of a normal distribution.

Figure 3.45: Mean generation frequencies of 5th-order fragments by each training group.

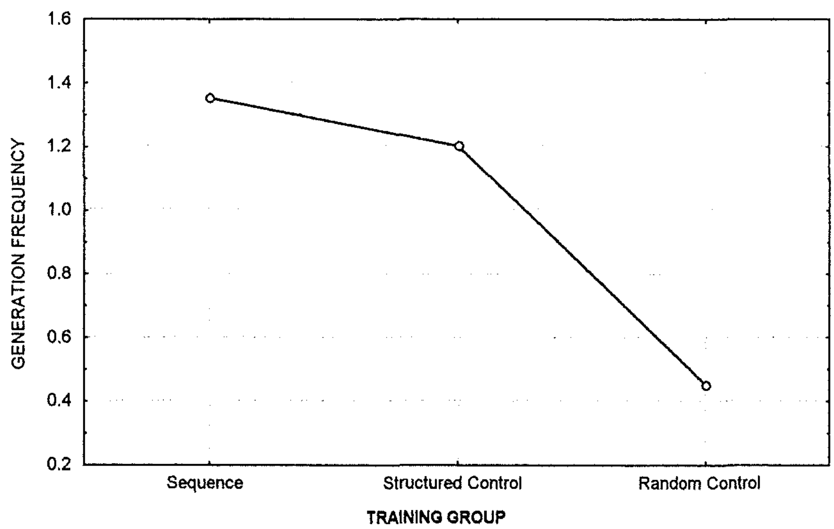


Figure 3.45 above indicates the possibility that sequence and structured control participants are able to generate more 5th-order fragments than can participants in the random control group. However, the generation frequencies are very low, and this result may not be statistically reliable. Thus, it can only be said that the sequence and structured groups appear able to generate sequence or frequency information above chance performance up to the 4th-order fragment level.

<u>Effect of Training Type on Explicit Knowledge:</u>

In summary, at the 1st-order relative frequency level only the structured control group appeared able to report the greater frequency of the D and A positions through their generation performance. This was evident also at the 2^{nd}-order level of generation performance, with only the structured control participants demonstrating knowledge of the more common DA transition. However, both the sequence and structured control groups generated significantly more sub-sequences of length three and four than the random control group in the generation task. The structured control participants were presented with a series that matched the repeating sequence only in the 1^{st}- and 2^{nd}- order frequency information.

It appears from the generate task that the structured control participants gain benefits from their relative frequency knowledge up to the 4^{th}-order fragment level, matching the performance of the sequence participants. Structured control participants may display this level of knowledge due to their knowledge of the subset of 2^{nd}-order transitions used. This is because these participants were presented with a smaller selection of 4^{th}-order combinations in training (including the target sequence fragments) than the random control participants due to the limited subset of 2^{nd}-order transitions. However, the 4^{th}-order combinations presented to the structured control participants would have varied considerably compared to the twelve encountered by the sequence participants. The fact that the structured control participants performed to the level of the sequence participants, despite encountering the 4^{th}-order fragments less frequently (and out of the context of a repeating sequence), demonstrates the importance of this relative frequency knowledge.

If the sequence participants had demonstrated facilitated performance (compared to the random control group) for the 1^{st}- and 2^{nd}-order generation, then it would be tempting to conclude that the learning of simple relative frequencies alone explains higher order generation abilities. However, as sequence participants appeared to exhibit no evidence of relative frequency knowledge, explicit knowledge of intact sequence fragments, not component transitions, must account for this facilitation.

Overall, it appears that structured control participants are explicitly aware of the relative frequency of the lights and movements they encountered during training, while those trained with a repeating sequence appear unaware of the same relative frequency information when it is embedded in a repeating sequence. The information explicitly learned by the sequence participants appears to be higher order segments of the sequence. One explanation for this unexpected result could be that without higher order structure imposed during training, the relative frequency information is more salient to the structured control participants than to the sequence participants. The sequence participants on the other hand, have some awareness of the existence of a more complex structure inherent in the training blocks. Effectively, imposing greater structure on the training series makes frequency information less obvious in the quest to master the higher level information.

3.5 *The Role of the Secondary Task*

The purpose of the secondary task in implicit learning studies is to discourage the acquisition of explicit sequence or frequency knowledge. Therefore, it is important to assess whether the secondary task did actually reduce explicit knowledge.

Firstly data from the structured interview were examined. Participants from the sequence and structured control groups were classified according to the explicit knowledge they demonstrated. Relative frequency information was broken down into 1^{st}- and 2^{nd}-order information which refer to knowledge of the frequencies of individual lights and light transitions. Sequence knowledge reflects the ability to report fragments of at least length three. A participant who gave fragmentary sequence knowledge in addition to 2^{nd}-order frequency information in the structured interview was classified as possessing 'sequence knowledge'. The assumption was made that 3^{nd}-order fragment knowledge is knowledge of a greater magnitude than 2^{nd}-order frequency knowledge, which is in turn greater than 1^{st}-order knowledge. This follows from the ordering of the information according to fragment lengths. The scores 0-3 were used for each participant to indicate their level of explicit knowledge, from none through to fragment knowledge. Structured control participants were never classified as possessing sequence knowledge. This was because they were trained with a series from which only relative frequency information (not a repeating sequence) could be learned.

Refer to Table 3.50 below for an illustration of the distribution of participants in each group according to this categorisation.

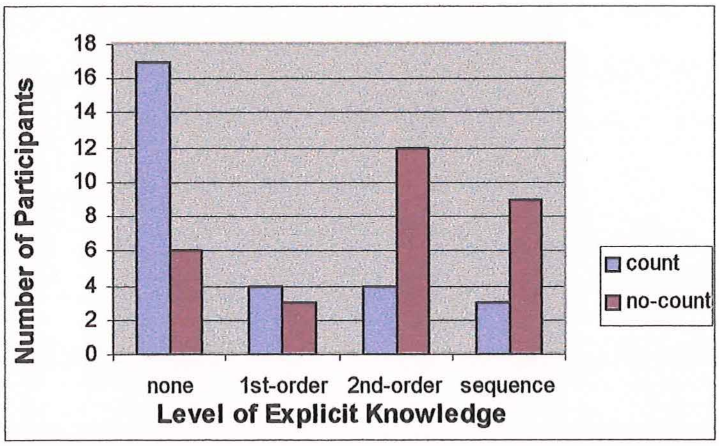
The prediction was that no-count participants would be able to report knowledge of a higher level, if the secondary task did impede the development of explicit knowledge for the count participants.

Table 3.50: Distribution of participants with explicit knowledge within the sequence and structured control conditions.

TRAINING	EXPLICIT KNOWLEDGE	secondary task count	secondary task no-count
sequence	sequence	5	9
	2nd-order	0	4
	1st-order	2	3
	none	13	4
structured	sequence	0	0
	2nd-order	4	8
	1st-order	2	0
	none	4	2

Figure 3.50 below presents the distribution of count and no-count participants when they are classified according to the four levels of explicit knowledge.

Figure 3.50: The number of participants in the count and no-count groups giving each type of explicit knowledge in the structured interview.



Participant explicit knowledge scores were treated by a training group (sequence and structured control groups only) x secondary task anova. This revealed that the secondary task requirement impacted on the level of explicit knowledge the participants later demonstrated, $F(1,56) = 6.80$, $p<.05$. From figure 3.50 it can be seen that the explicit knowledge levels of the count participants were distributed more toward the lower end of 'no explicit knowledge' when compared to no-secondary task participants. No effect of training group was found. It appears, from the structured interview direct test, that the counting task diminished the level of explicit sequence and 2^{nd}- order frequency knowledge.

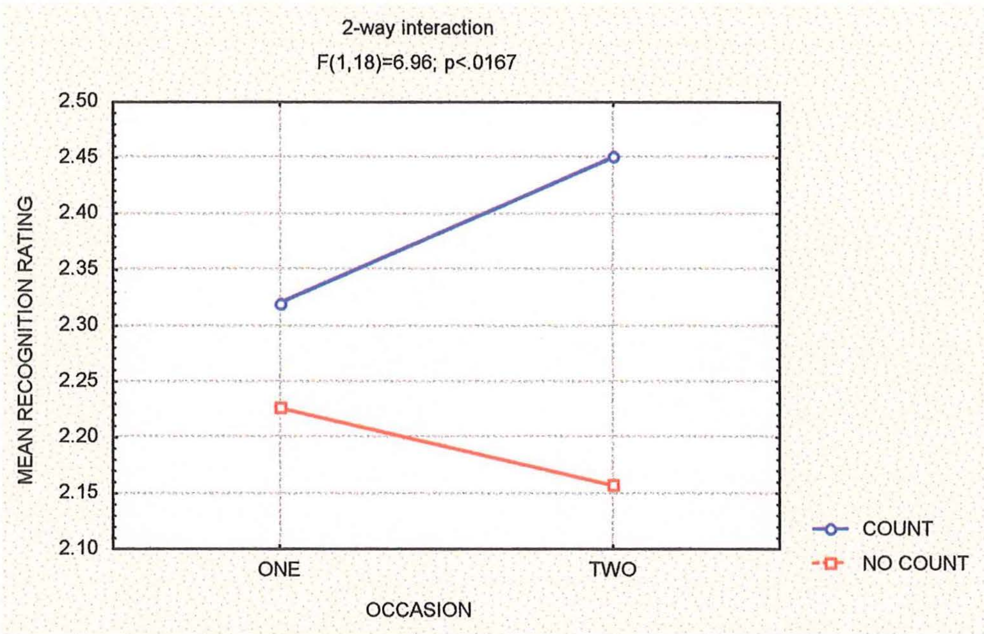
However, when the recognition test is used to indicate explicit knowledge, a different conclusion is reached. The secondary task factor was included in the anovas examining the rating differences between target and foil fragments, and between fragments including and not including the DA transition. Explicit fragment knowledge was indicated by a difference in familiarity rating for target and foil fragments when they did not include the DA movement. Additionally, explicit knowledge of the more frequent DA transition was revealed by participants rating fragments containing the transition as recognised. If the counting task impedes the development of explicit fragment knowledge, then interactions would be expected between the secondary task and target-foil and DA vs. non-DA variables. When fragment ratings were treated by a count-no count x target-foil x DA vs. non-DA x occasions anova, no interaction involving the count-no count and target-foil or DA vs. non-DA factors neared significance. This indicates that the secondary task does not impede the acquisition of explicit sequence knowledge as measured by the recognition task.

However, the anova did reveal an interaction between secondary task and occasion, $F(1,18)=6.96$, $p<.05$. Figure 3.51 below demonstrates that this interaction is due to the no-count participants rating recognition test fragments closer to the 'definitely recognised' end of the rating scale on the second occasion, while the count participants show the reverse trend. Perhaps the effect of the secondary task is to make participants less confident of their recognition performance over time. However, it is interesting that no-count participants instead come to rate fragments as more strongly recognised. This effect is not differential for foil and target recognition fragments, or DA and non-DA fragments. The difference in the scale ratings between and within the two secondary task groups is not numerically large, refer to Table 3.51 below. This is reflected in a non-significant secondary task main effect.

Table 3.51: Mean recognition ratings and standard deviations for the two secondary task groups on both recognition task occasions.

		OCCASION	
		one	two
COUNT	mean	2.32	2.45
	standard dev	1.00	1.02
NO COUNT	mean	2.23	2.16
	standard dev	1.16	1.09

Figure 3.51: Mean recognition ratings on both occasions of the recognition test for the count and no-count participants.



Similarly, an analysis of results from the generate task revealed that the secondary task did not impact on the frequency with which sub-sequences were produced. This was evident by non-significant effects pertaining to the secondary task within anovas examining the number of fragments of each length generated by each participant for the three training groups. The secondary task also failed to have an effect on the generation of the particular 1st- and 2nd-order fragments that were presented more often during training for the sequence and structured control participants. Moreover, no effect of the secondary task on the generation of the DA, ADA, and AEC fragments, (differentially generated for the three training groups), was found.

While the secondary task appears to meet the objective of decreasing explicit knowledge in the structured interview, it fails to do so when explicit knowledge is assessed by the recognition and generate tasks. The structured interview could be considered a less sensitive measure of explicit knowledge (Shanks & St. John, 1994). Possibly the secondary task impacts only on this verbal recall measure precisely because it takes more confidence to report information, (the rationale for considering it less sensitive). If so, the structured interview as a measure of explicit knowledge is contaminated by participant confidence.

3.6 *Agreement Between the Three Direct Tests of Explicit Knowledge*

Another objective of this research was to ascertain the concurrent validity of the measures of explicit knowledge. This is important as debates within the implicit learning domain query which measures of explicit knowledge are the most appropriate. The particular measures used are not standard across different studies within the area, and if these measures do not show consistent agreement then conflicting findings from the different studies may in part be due to the particular measures of explicit knowledge that were used.

This comparison between the direct tests in this study is confined to assessing the agreement between the structured interview and the recognition test, and the interview and the generate task. The direct comparison of the generate and the recognition tasks cannot be performed because different sets of participants completed each test. Moreover, the recognition task was designed to assess only fragmentary sequence knowledge. The generate task, on the other hand, is also sensitive to relative frequency information.

Recognition Test and Structured Interview:

One way to assess agreement between the interview and recognition tasks as measures of explicit knowledge is to assess the relationship between target-foil rating differences with the level of explicit knowledge displayed in the structured interview. Greater target-foil differences should be associated with a higher level of explicit knowledge. To do this, participants were classified according to the highest level of explicit knowledge evident from the interview. (Refer to the previous section on secondary task effects for details as to how the participants were classified). The recognition performance of participants classified as either having no knowledge or sequence knowledge in the structured interview were examined. Participants demonstrating either 1^{st}-or 2^{nd}-order information as their highest level of explicit knowledge in the interview were excluded as this knowledge is of no benefit to recognition task performance. Mean target-foil rating differences (recognition task) as a function of the two levels of explicit knowledge (structured interview) are presented below in table 3.60.

Table 3.60: Mean target-foil rating differences (and standard deviations) for participants demonstrating no explicit knowledge or sequence knowledge in the structured interview.

	None	Sequence
Mean	.17	.13
Standard Dev.	.46	.32

There appears to be no association between level of explicit knowledge and target-foil difference. An anova, (level of explicit knowledge from the structured interview x target vs. foil), was conducted on the mean target and foil ratings and revealed no significant interaction between level of explicit knowledge from the structured interview and target-foil recognition ratings. However, a significant main effect of explicit knowledge from the structured interview ($F(1,13)=6.88$, $p<.05$) reflects the tendency for participants with demonstrated sequence knowledge to more readily rate fragments (regardless of whether they were targets or foils) as recognised.

Explicit knowledge measures within each participant were examined for the structured interview and recognition task. Participants were classified according to whether correct information had been given during the structured interview, and whether they had rated one or more target fragments as 'definitely encountered during training' on both recognition task presentations. Table 3.61 presents the distribution of participants for explicit knowledge in the two direct tests according to these classifications. All participants who demonstrate explicit knowledge in the structured interview also do so in the recognition task. However, only a subset of participants with explicit knowledge in the recognition test demonstrate explicit knowledge in the structured interview. This may reflect the tendency for the structured interview to be less sensitive (recall versus recognition measure) to information that the participants may not be highly confident about.

Table 3.61: The distribution of participants according to demonstrated explicit knowledge in the structured interview and the recognition task.

		RECOGNITION TEST	
		Definitely Recognised	Not Definitely Recognised
STRUCTURED	Information Given	7	0
INTERVIEW	No Information Given	8	5

A detailed examination of individual fragments was also undertaken. For all seven participants, information given in the structured interview (such as a particular transition) also featured in at least some of the recognised fragments.

Analyses reveal that explicit sequence knowledge demonstrated in the structured interview is associated with greater likelihood of rating a fragment as recognised in the recognition task. However, this sequence knowledge does not appear to be related to an enhanced ability to differentiate sequence fragments from foils. While the recognition test yields more participants who demonstrate explicit knowledge, there is reliable overlap in the particular knowledge volunteered when participants do indicate knowledge on both tests. This suggests that the two tasks are measures of explicit knowledge, but that the structured interview is a relatively less sensitive measure.

Generate Task and Structured Interview:

The following analyses were undertaken to establish the relationship between explicit knowledge assessed from the interview and generate tasks. Again participants were classified according to the highest level of knowledge indicated in the structured interview (no information, 1st- and 2nd-order frequency, and sequence information). A one-way anova was performed examining the effect of the level of explicit knowledge reported in the structured interview on the total number of 2nd-order sequence chunks generated by each participant. Separate one-way anovas were also performed in this way on the total number of generated 3rd-order, and 4th-order, fragments. No significant effects relating to explicit knowledge from the structured interview were obtained.

It was considered relevant to examine the agreement between the particular information yielded in the structured interview and generate task for each participant. A problem with the generate task is determining what frequency of generation by a participant is required to indicate explicit knowledge of a fragment (or relative frequency of a particular transition or light). This was achieved by comparing frequency of generation of various fragments produced by structured control and sequence participants with those in the random control group. A fragment was said to be explicitly generated when its frequency of generation exceeded the 95th percentile of the frequencies generated by the random control group for the particular fragment. Information obtained in this way from the generate task was then compared to responses given in the structured interview.

Table 3.62 and Table 3.63 below categorise participants according to whether they demonstrate explicit knowledge in the generate task when these criteria are used. The distribution of participants with and without explicit knowledge on the two direct tests is then evident. These tables clearly show that the generate task yields explicit knowledge from more participants than the structured interview.

Table 3.62: The distribution of sequence participants according to whether they demonstrate explicit knowledge in the structured interview and the generate task.

SEQUENCE GROUP		GENERATE TASK	
		Knowledge	No Knowledge
STRUCTURED	Knowledge	7	1
INTERVIEW	No Knowledge	8	4

Table 3.63: The distribution of structured control participants according to whether they demonstrate explicit knowledge in the structured interview and the generate task.

STRUCTURED CONTROL GROUP		GENERATE TASK	
		Knowledge	No Knowledge
STRUCTURED	Knowledge	12	2
INTERVIEW	No Knowledge	6	0

When the particular information yielded from the generate task was examined, only three sequence participants indicated knowledge of the relative frequency of the D, A and DA occurrences. This compared to twelve of the 20 participants in the structured control group. At the fragment level, 14 sequence and 18 structured control participants generated sequence information reliably above that of the random control group. Again, this reiterates the finding that structured control participants show evidence of relative frequency information (which underlies their performance at the fragment level), while in the main sequence participants demonstrate fragment knowledge only.

When this information is related to information volunteered in the structured interview for participants who indicated knowledge on both tasks, high agreement between the particular pieces of information yielded in both tasks is found. Nineteen participants demonstrated correct explicit knowledge on both direct tests. Of the nineteen, only three (structured control) participants volunteered information in the structured interview which was not featured within the particular information yielded from the generate task, (refer to Table 3.64). Twelve participants (five sequence and seven structured control) volunteered at least 2nd-order frequency information or one movement during the structured interview in common with the fragments produced in the generate task. Four further participants (two in each group) had a 3^{rd}-order (or longer) fragment in common between the two tasks.

Table 3.64: Distribution of participants according to agreement between the particular information volunteered in the structured interview and information yielded in the generate task.

	AGREEMENT		
TRAINING GROUP	None	2nd-Order	Fragments
Sequence	0	5	2
Structured Control	3	7	2

While analyses fail to demonstrate a relationship between the level of explicit knowledge evident on the structured interview and the performance on the generate task, agreement in the particular information extracted from the two tasks is high. The majority of participants who volunteered correct information in both direct tests demonstrated a high level of consistency between information yielded from the generate task and information given in the structured interview. Completion of the generate task resulted in a higher frequency of participants classified as possessing explicit knowledge than the corresponding structured interview. It appears that the generate task is a more sensitive measure of explicit knowledge than the structured interview.

Conclusion Regarding Direct Test Agreement:

It would seem then that ability to demonstrate explicit knowledge on both the recognition and the generate task cannot be predicted by the level of explicit knowledge in the structured interview. While this appears damaging to the concurrent validity of the two measures, a relatively high agreement was found between the content of the particular information yielded between both the recognition task and the structured interview, and the generate task and the structured interview.

3.7 Linking Explicit Knowledge to Decision Time

The rationale behind the attempt to link explicit knowledge to decision time lies in the theory posited by Leadley (1997). Leadley proposed that decision time would decrease only as a reflection of the ability to correctly predict the location of the next stimulus. Thus, explicit knowledge of sequence information should yield a decrease in decision time.

This leads to predictions at three levels.

- At a group level, a training group with a tendency to exhibit explicit knowledge should demonstrate reduced decision times.
- Within each training group, participants with the ability to give relevant explicit knowledge in the direct tests should show shorter decision times.
- And at the most sensitive within-participant level, certain items of information given in the direct tests should produce shorter decision times in comparison to training movements which were not found to be explicit.

Earlier analyses failed to produce a training group effect on DT, revealing no impact of explicit knowledge at the group level. This leaves the remaining two levels to be investigated.

Explicit Knowledge from the Structured Interview:

To assess the relation between decision time and explicit knowledge reported in the structured interview, participants were categorised according to the highest level of explicit knowledge they were able to indicate in their replies to the structured interview (refer to section regarding the secondary task effects for categorisation details).

An explicit knowledge type x secondary task x block anova was performed which compared decision times for participants according to the different types of explicit knowledge. No effects pertaining to type of explicit knowledge was found. This was true also when a separate analysis was performed on the sequence and on the structured control group data.

At the more sensitive within-participant level of analysis, decision times for correct reported movements in the structured interview were compared to the movements not reported for each participant. No significant effect of whether the movements were correctly reported was found in a secondary task x training group x explicit knowledge x block anova on decision time data.

Recognition Task:

On the basis of recognition ratings, participants were classified into those having explicit sequence knowledge, and those not having explicit sequence knowledge. Those rating at least one target fragment as 'definitely encounter in training' on both occasions were classified as having explicit fragment knowledge. Table 3.70 presents the frequencies of participants according to this classification. An explicit knowledge x secondary task x block anova was performed on the median DTs (obtained from each block for each participant). No effect involving explicit knowledge approached significance.

Table 3.70: Numbers of participants classified as having or not having explicit fragment knowledge for the two secondary task groups.

	Knowledge	No Knowledge
Count	6	4
No-Count	9	1

An attempt was then made to assess DT differences for explicit versus not-explicit fragments for each participant. Leadley (1997) furthered her analysis of the recognition task by relating the definitely recalled fragments to their corresponding decision times, postulating that the decision times for these fragments would be shorter than those relating to non-recognised sub-sequences. This method of analysis was employed in this study also, with fragments that rated 'definitely recalled' (a rating of 1) in both recognition task occurrences constituting the fragments considered for this analysis. Of these fragments only those that had one or more adjacent, overlapping sub-sequences rated as definitely familiar were used. This criterion for explicit knowledge relating to specific fragments of the sequence (also used by Leadley 1997), resulted in four secondary task, sequence participants, and seven no-count participants supplying fragments for decision time analysis. The average number of adjacent and overlapping fragments recognised for the secondary task sequence group was 1.5, and 3 for the no-secondary task condition.

Decision times for all lights within the recognised fragments were compared to those for unrecognised portions of the sequence (fragments that rated '4=definitely not recalled from training' in both recognition task repetitions). The first light in each fragment was excluded from this analysis as this light allowed the prediction of the following lights, so only the decision times of the consequent lights were relevant here. This comparison was achieved by the calculation, for each participant, of median decision times over all the recognised fragments and over all the unrecognised fragments for each block, and enabled one to ascertain whether decision times decreased more rapidly for the explicitly learned components than the unrecognised fragments. A secondary task x recognised vs. non-recognised fragments x blocks anova was performed. Only the blocks effect was significant. Thus, more rapidly decreasing decision times do not appear to be a feature of the fragments classified as being associated with explicit knowledge from the recognition task in this experiment.

Generate Task:

To assess whether explicit knowledge as indicated by the generate task affects DT, participants were categorised according to whether they demonstrated explicit knowledge in the generate task. If a participant surpassed the 95 percentile cut-off from the random participant generation for any one fragment, they were deemed as exhibiting explicit knowledge. DTs for these participants were compared with those who did not show explicit knowledge in the generate task using this criteria. No effect of explicit knowledge on DT was found in a secondary task x explicit knowledge x block anova.

Additionally, for all participants, DTs for the DA transition (which was commonly associated with explicit knowledge in the generate task) were compared with DTs for all other transitions. The training group x secondary task x DA vs. all other transitions x blocks anova did not reveal any relevant significant effects, suggesting that the DA movement was not associated with shorter DTs.

At the within-participant level, decision times for generated and non-generated movements, were compared over all forty sequence and structured control participants who performed the generate task. A generated sequence fragment of three lights or longer constituted the 'generated movements.' The decision time for the first key-press in the chunk was discarded from the 'generated movements' group if it did not overlap with another chunk produced by the same participant. This was to keep the criterion used here for explicit knowledge in line with that used in the recognition task. A training group x generated/non-generated movements x secondary task x block anova was performed. Aside from the significant effects of block and the interaction between block and presence of a secondary task, (found already in analyses of DT) only one interaction reached statistical significance. The three-way interaction between training group, whether the movement had been generated, and block was significant, $F(10,240) = 2.76$, $p<.01$. The predicted illustration of this interaction if explicit knowledge was reflected in DT, would be a differential decrease in DT for the generated and non-generated fragments. This effect would be stronger for one of the two training groups. Figures 3.70 and 3.71 below show that no clear interpretation of this interaction can be made linking shorter decision times to explicit knowledge as indicated by generated sequence chunks.

Figure3.70: Mean DTs for sequence participants per block for generated and non-generated fragments:

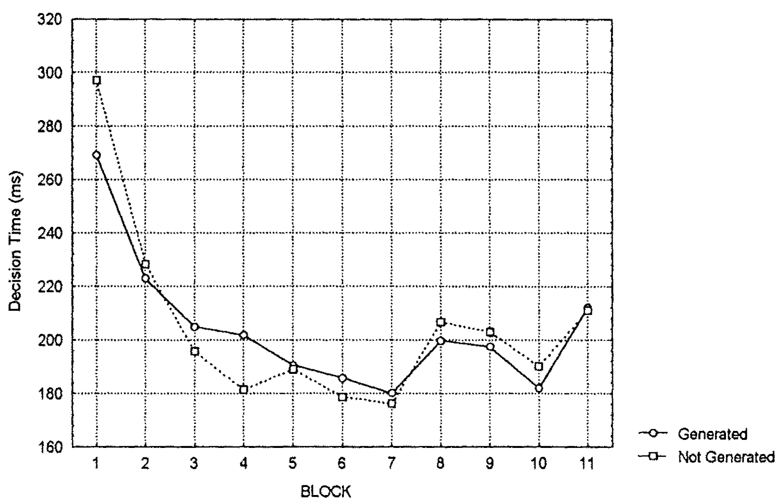
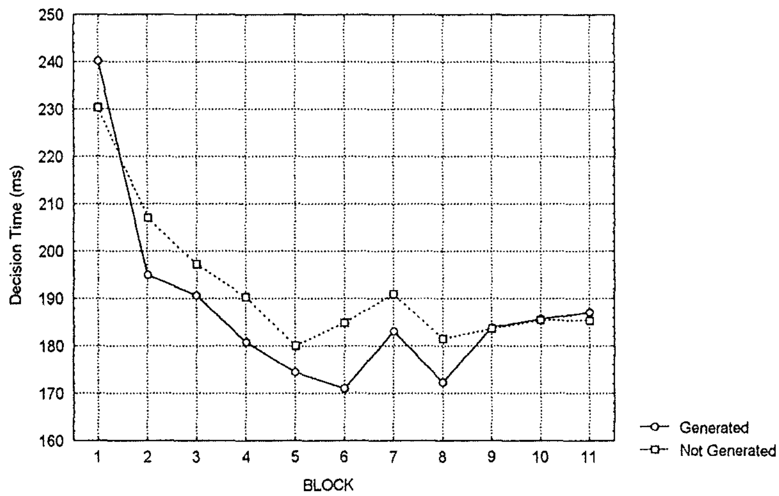


Figure 3.71: Mean DTs for structured control participants per block for generated and non-generated fragments:



As found with the recognition task then, decision time has not been linked clearly with indicators of explicit knowledge.

Anticipation Errors:

One last attempt was made to link decision time to explicit knowledge through the examination of anticipation errors.

It was postulated that explicit knowledge may be reflected in more anticipation errors or greater magnitude of anticipations for the structured control or sequence group, as compared to the random group. This prediction was not borne out when training group x secondary task x block anovas were conducted on the size and on the number of anticipations for each participant.

The generation task highlighted the possibility that structured control participants had explicit knowledge of the relative frequency information that the DA transition occurred more frequently than any other possible movement. Shorter DTs were not linked to this movement in this experiment. However, it was postulated that the DA movement may be linked to a greater frequency or greater degree of anticipation errors amongst the participants who were aware of this frequency information. It was thought that the structured control group would differ from the sequence and random control groups with regard to the pattern of DA anticipations in comparison to anticipations for all other transitions.

A training group x DA vs. other transitions anova on the magnitude of anticipation errors revealed no significant difference in the size of the anticipations for the DA transition, as compared to other movements, for the three different training groups.

The frequency of anticipation errors for participants within each training group were converted into scores according to their relative opportunity of occurrence. Light A followed light D on one trial in every six for the sequence and structured control participants, and one trial in 20 for the random control group. On analysis of the resulting proportional frequencies of anticipation errors, an anova failed to reveal significant effects relating to the DA transition, as compared to all other transitions.

Anticipation errors were considered as plausible indicators of predictive knowledge and an attempt was made to link the number and magnitude of these errors to DT measures. Decision time does not appear to reflect explicit knowledge as measured from the three direct tests used in this study or as indicated by anticipation errors.

4.0 DISCUSSION

This thesis incorporated five aims relevant to current issues within the sequence learning research area. These were as follows:

1) Determine the degree to which explicit learning is evident in a sequence learning paradigm.
2) If explicit learning does occur, what information contained within the sequence is learned?
3) What effect does imposing a concurrent task on the SRT have on explicit sequence learning?
4) Compare the three direct tests of explicit knowledge for an informal assessment of concurrent validity.
5) Verify and extend the reflection of explicit sequence knowledge in decision time measures demonstrated by Leadley (1997).

The outcomes from each of the five areas are outlined below.

4.1 Extent of Explicit Knowledge

Results from the structured interview show that some, but not all, participants presented with a repeating sequence, or with the structured control, are able to give verbal accounts, which show evidence of explicit learning. The recognition task, which could not be applied to structured control participants, also indicates that sequence participants exhibit explicit learning regarding the SRT sequence. Lastly, the generate task provided evidence of explicit learning of relevant SRT information by both the structured control and sequence participants.

Three different direct tests of explicit knowledge have, in this experiment, revealed the existence of explicit learning during a sequence learning paradigm. These three tests differ in their characteristics, and their sensitivity. Each is associated with different, but valid, criticisms as methods for evaluating explicit knowledge in their own right. Even the most insensitive test of the three (the structured interview) which is the most likely to result in a false conclusion that no explicit learning is present, (Shanks & St. John 1994), illustrated that explicit knowledge occurred in this sequence learning study. Together these direct tests show that explicit learning does occur in a sequence learning paradigm such as the one used in the present study. Even more compelling is the fact that in comparison to the typical sequence learning experiment, the one employed here would perhaps be considered difficult to learn. This is due to the incorporation of a variable as opposed to a fixed response-stimulus interval, and the use of a lengthy (12-long) sequence without embedded unique transitions.

This clear evidence of explicit knowledge in a difficult sequence learning experiment could lead to the conclusion that at least some explicit knowledge is endemic in the typical ten-long, fixed response-stimulus interval, sequence learning study. Participants may be classed as unaware simply because researchers have failed to tap the appropriate knowledge with regard to information embedded within the sequence (i.e. frequency knowledge) or have failed to use a test sensitive enough to reveal the explicit knowledge present in these so-called unaware participants. This view is in line with the information and sensitivity criterion espoused by Shanks and St. John

(1994). Indeed this experiment which seeks explicit knowledge of frequency information, as well as the typical sequence chunk information, illustrates that explicit knowledge may be more prevalent than currently assumed. Future research should consider probing frequency as well as higher-order sequence knowledge with direct tests. This is not to assume that these two types of information exhaustively describe explicit learning, as other dimensions may well be relevant for exploration also. Until more is known about the prevalence of explicit knowledge in sequence learning experiments, and which information embedded within a sequence is amenable to explicit knowledge, identifying participants as unaware may be premature. Therefore, gross comparisons of aware and non-aware groups may not be presently viable.

4.2 What is learned explicitly?

To develop a greater understanding of the role of explicit knowledge in sequence learning paradigms, it is important to ascertain what information embedded within a sequence is amenable to explicit learning.

The structured interview highlights that structured control participants can verbalise knowledge with regard to the relative frequencies of stimuli and movements between stimuli. The sequence participants are evidencing explicit knowledge at least at the relative frequency level. However, from this test alone, it was not possible to ascertain that higher order sequence chunks were learned by sequence participants.

The recognition test indicates that sequence information is learned by sequence participants. While the particular test that was used could not directly assess explicit knowledge of relative frequencies, the pattern of results obtained allude to the possibility that sequence participants learned the more frequent DA movement. Whilst, from the structured interview, one could not conclude for certain that higher order sequence information is learned by sequence participants, the results of the recognition test indicate that the sequence participants do attain this explicit knowledge.

Some intriguing results were obtained from the generate task. The structured control participants displayed explicit awareness of the relative frequencies of presented lights and movements of lights. The sequence participants, on the other hand, appear unaware of the relative frequency information embedded within their training sequence. This is not to assume that the sequence participants do not learn components of their sequence explicitly, as they demonstrate explicit knowledge of higher order sequence segments in the generate task. It appears that sequence participants learn sequence information at the expense of relative frequency information. Perhaps in imposing order on a set of stimuli we explicitly detect information present from the highest level of imposed structure. This information may be most salient and therefore be more easily learned, with lower level information being neglected in the process.

This finding appears more believable in the context of work involving word recognition, as opposed to sequences of light positions. This literature reveals that representations of words are formed prior to the complete processing of the individual letters, that make up the words (Johnson, Turner-Lyga, & Pettegrew, 1986). Moreover, Miller, Bruner and Postman (1954) found that the speed with which participants identify a string of letters depends on the degree to which the string approximates the natural occurrence of the letters within the English language. They postulate that the strings with higher-orders of approximations contain less 'bits' to process, indicating that participants do not rely solely on the processing of each individual component of the string. These studies, taken together with the findings from this experiment, indicate the possibility that when structure is present within a set of stimuli, participants do not process or learn the individual components in isolation, but learn it in coherent 'units'. Miller et al (1954) assert that the greater the structure imposed on the series of stimuli, the bigger the 'chunks'. In this way, structured control participants learned the relative frequencies of sequence components, while sequence participants processed and learned sequence chunks.

The findings from the generate task make the seemingly incongruent results from the structured interview and recognition test more easily integrated. The structured interview shows that sequence participants have explicit knowledge at least at the relative frequency level, with insufficient evidence to conclude that they demonstrate sequence chunk learning. From the generate task it would appear that these participants are learning at the sequence chunk level. This apparent disagreement between the structured interview and generate task may be resolved when one considers the commonly conceived criticism of the interview. Lack of confidence and the relative insensitivity of the structured interview may result in an underestimation of sequence participants' abilities. This could lead to explicit sequence knowledge being falsely 'down-graded' to relative frequency knowledge, and the false conclusion that sequence participants are only explicitly learning information pertaining to the relative frequencies of sequence components.

The recognition test confirms that sequence participants do learn higher order sequence information. However, participants only demonstrated the ability to differentiate foils from target sequence chunks when fragments that included the more common DA movement were removed. Whilst the recognition test in this experiment was designed to assess only sequence knowledge (not relative frequency information), evidence for explicit learning relating to one movement which did occur more frequently (the DA movement) was found. An incongruency appears between the recognition and generate tests. This is because results from the recognition test suggest that sequence participants have awareness of the more frequent DA movement in the absence of knowledge regarding the surrounding stimuli in which this transition is embedded. On the other hand, the generate test suggests sequence participants have explicit knowledge of the chunks but not the relative frequency of the chunk components.

The recognition test was designed in this experiment to assess explicit sequence knowledge by constructing foils that included only the transitions incorporated in the sequence. In this way, a control for relative frequency knowledge was attempted. The ability to separate the influence of frequency from sequence knowledge in the recognition test should be capitalised on for future research. Experiments could be designed which make use of both foils that only include sequence movements and those that incorporate movements that do not appear in the sequence. Careful analysis can then compare the recognition ratings of the targets, the foils that incorporate relative frequency information, and the random foils, to separate out explicit knowledge of frequency versus sequence information by sequence participants. In a similar vein the recognition test is useful as it can be used to assess the ability of structured control participants to distinguish fragments which include only viable movements from random combinations, and therefore make it possible for the researcher to conclude whether relative frequencies have been explicitly learned.

At this point, a discussion of how the results obtained here relate to those obtained by Shanks et al (1994) may be useful. Shanks et al (1994) used both structured and random controls in their study and found that sequence participants who exhibited 'full sequence knowledge' out-performed the structured control participants in the SRT. The sequence participants who failed to demonstrate explicit knowledge demonstrated SRT performance that was indistinguishable from the structured control participants. This tempts the conclusion that participants with sequence level knowledge learned this explicitly, while those with frequency level knowledge learned it implicitly. However, Shanks et al (1994) relied solely on the results of a structured interview for their classification of participants into 'full knowledge', 'some knowledge' and 'no knowledge'. Their study did not state whether frequency knowledge was probed for in the structured interview, and if it was, the prevalence of this knowledge was not outlined. The use of a more sensitive direct test, that allows the assessment of frequency knowledge, may alter the classification of these participants, and highlight more clearly the relation between explicit frequency knowledge and learning as demonstrated in the SRT.

Reed and Johnson (1994) claim that saliency of sequence components is highly related to the probability of developing explicit knowledge of the component. Cohen et al (1990) claim that unique transitions form salient 'flags' which allows the remainder of the sequence to be learned more readily. These assertions cannot be tested in this experiment, as no unique components were included within the sequence. However, Cohen et al (1990) found that ambiguous sequences, such as the one used here, were not associated with learning when a secondary task is performed concurrently during training. Evidence of learning was not found from the training component of this experiment. However, explicit learning appears to occur. So whilst it may be true that sequence learning, as assessed from SRT performance, may not occur with a secondary task when unique transitions are absent, explicit awareness of ambiguous sequence components has been demonstrated in this experiment.

Perruchet and Amorim (1992), in the first use of the free generate task, found that sequence participants (as a group) did demonstrate explicit learning of both sequence chunks and frequency information. What is of most interest from their study, however, is that one of their experiments used a sequence that incorporated unique transitions of the type considered salient by Cohen et al (1990). Perruchet and Amorim (1992) concluded from the sequence participants' generation performance, taken together with corresponding TRT decreases, that these unique transitions were not learned in isolation, but were represented within the larger context of third-order chunks. This finding does not discount the possibility that the unique transitions were used initially as salient flags from which larger sequence chunks were learned. These sequence chunks could then have become the salient units at the expense of the transitions. The finding that lower order frequency information was sacrificed for higher order sequence knowledge in this case, adds weight to the findings presented in the current study. The issue with regard to the learning of unique transitions is one worth pursuing further in future research. Moreover, Perruchet and Amorim's (1992) finding that explicit knowledge was reflected in TRT measures was an exciting discovery, and one that relates closely to what the present study hoped to achieve on a more detailed within-participant level with decision time.

Reed and Johnson (1994) posit that reversals (such as ECE) within a sequence are highly salient and are likely to be learned. The generate task in this experiment did not support this assertion. While explicit knowledge was commonly associated with the ADA reversal in this study, this is probably due to the inclusion of the most common DA transition within the reversal. The ECE reversal, which is not confounded with transition frequency, was not typically associated with explicit knowledge. Whilst relative frequency information was learned explicitly in this study, primarily by structured control participants, reversals were not. Assumptions made by researchers regarding what is likely to be learned by participants need experimental exploration to validate them. Further investigation into what information is learned explicitly would be valuable, especially before assessing which information can be learned implicitly.

The most pertinent finding of all with regard to what information is learned explicitly, is that sequence participants explicitly learn higher order sequence information at the expense of relative frequency information. Yet, the structured control participants demonstrate in this study, that the frequency information is amenable to explicit learning. Moreover, this knowledge resulted in structured control participants performing on the various direct tests in a manner which was nearly indistinguishable from the sequence participants, until the results are closely analysed to examine the separate contributions of sequence and relative frequency knowledge. This suggests that the simple act of adding a structured control to a sequence learning paradigm and comparing direct test performance to decide if sequence participants learned anything aside from relative frequency information, is not sufficient. The direct test results need to be analysed carefully to ascertain the exact roles that relative frequency and sequence information play. It may be, as in this experiment, that structured control and sequence participants are able to perform equally as well in the direct tests, while both utilising different explicit knowledge bases in performing these tests.

It was thought that previous experiments that claim sequence learning in the absence of explicit knowledge may do so because explicit knowledge of relative frequencies went untested. Together the findings from this study indicate that this is unlikely. Sequence participants did not display explicit relative frequency knowledge in the absence of higher order sequence knowledge. However, future researchers may be wise to incorporate a control more relevant to the conclusions they are pursuing, such as a structured control in place of random control. Alternatively for a fuller picture of the learning processes involved, both controls could be utilised as this study has done, along with a full examination of participants' explicit knowledge.

4.3 Secondary Task Effects

The use of a concurrent task such as tone counting during the SRT is assumed to eliminate or at least diminish explicit learning, (e.g. Frensch et al 1994, McDowall et al 1995). This study was designed to examine the validity of this assumption.

The results of the structured interview appeared to support the use of a secondary task to decrease the amount of explicit sequence learning. Participants exposed to the concurrent tone counting task volunteered less information in the structured interview task.

However, the recognition test failed to demonstrate a decrease in explicit knowledge due to the secondary task. These participants did not show diminished ability to differentiate foils from fragments when the confounding influence of fragments containing the DA movement was removed from the analysis. What did emerge from this recognition test was an intriguing pattern of results involving the secondary task and the ratings given on the two different repetitions of the recognition task. It appeared that over time secondary task participants become less confident of their ability to recognise fragments, and both foil and target fragments are rated further toward the less recognised spectrum on the second occasion. On the other hand, participants not exposed to the secondary task became more confident of their abilities and rated all fragments (foil and target) as more confidently recognised over time. This result suggests that the secondary task might impact not on the level of explicit knowledge attained by participants during the SRT, but instead acts to lower the confidence that participants have in the explicit knowledge they demonstrate.

The possibility of the secondary task impacting on confidence levels can be reapplied to the structured interview results. This direct test has been criticised as it is believed that the explicit knowledge participants possess can be underestimated on the structured interview (Shanks & St. John 1994), with participants not reporting valid information that is associated with low confidence levels. The difference between the explicit knowledge attained from the interview for secondary task and non-secondary task individuals in this experiment may simply reflect two groups of participants with similar levels of explicit knowledge but differing confidence levels. It is well established that people can recognise what they cannot recall (Nelson 1978).

In line with the assertion that the secondary task did not impact on explicit knowledge in this study, participants who did or did not perform the tone counting task could not be differentiated by their generation task performance.

The results of the three direct tests used here taken together, point to the position that the secondary task fails to diminish the level of explicit sequence or frequency information attained by participants in a repeating sequence SRT. Instead the concurrent task may give the impression of decreasing this knowledge by acting to erode participant confidence in the explicit knowledge that they do possess when using the structured interview task.

The secondary task may appear to influence learning during the progression of the SRT in experiments by impacting on rates of learning or slowing participants' responses to the stimuli during training. It is difficult to make conclusions about the secondary task's impact on the demonstrated learning during the SRT in this experiment, because learning was not evidenced from DT or TRT measures. Therefore, this study did not demonstrate a faster rate of learning for the participants without a secondary task compared to those that counted tones. The secondary task did act to slow participants' responses over all eleven training blocks, both in terms of decision time and total reaction time. The first block was dissected to ascertain whether non-secondary task participants were responding more speedily due to rapid sequence learning occurring during the first block alone. This was not evidenced, indicating that the response times for the secondary task participants were slowed from the very onset of the experiment, before participants had the opportunity to learn. This suggests that the secondary task does not impact on learning but instead acts simply to slow participants in their decision and response times. This is in line with Jonide's (1995) belief that the secondary task acts simply to slow the ability to respond to stimuli by occupying working memory so that participants must deal with the secondary task before being able to complete the next response in the SRT.

Cohen et al (1990) claim that the secondary task acts to disrupt learning of the associations between consecutive stimuli, particularly for ambiguous sequences. If this were the case, one would expect learning of 1st-order transitions only. This study has shown that sequence participants in a stimulus response task involving a secondary task and a twelve-long ambiguous sequence learn higher-order sequence information. It seems unlikely that the secondary task serves to disconnect individual sequence stimuli so that they are learned out of the sequence context.

From this study, one could conclude that the secondary task does not meet its objectives of diminishing explicit sequence learning, instead acting to slow participants' decision times and responses and to diminish the level of confidence associated with valid explicit knowledge. Future research should perhaps examine the actions of the secondary task more closely before incorporating the task into experiments for the purpose of retarding or preventing explicit knowledge acquisition.

4.4 Comparison of direct tests of explicit knowledge

There is not one direct test of explicit knowledge alone that is immune to criticisms or shortfalls. For that reason this experiment utilised three differing direct tests so as not to rely on any one inadequate test. In incorporating three differing tests this study provides the opportunity for an informal comparison of the results each test yields. Varying, incongruent conclusions from other studies may in part be due to the different directs tests used which may give conflicting outcomes. This study was not designed specifically to compare the structured interview, recognition and generate tasks, but nevertheless the belief was that valuable insights into the agreement between these tests might be achieved.

Direct comparisons could not be made between the generate and the recognition tests because different groups of participants completed each test. Perruchet and Amorim (1992) compared across participants in this manner and obtained fairly low correlations between the two tests (maximum of 0.27 for five-trial sequences). Perruchet and Amorim (1992) themselves state that their correlation values were fairly inaccurate due to the small number of value pairs on which their correlations were based. A comparison of this nature across different participants was considered to add little value within the context of the present study. Instead closer consideration, in future work, should be given to devising new methods (if any are possible) to assess the agreement between the recognition and free generate task at a within-participant level.

When comparisons were made between the results of the structured interview and the generate and recognition tests, it was found that the level of knowledge exhibited on the interview did not relate to performance ability on either the generate or recognition direct tests. That is, the ability to provide sequence level information, as opposed to just frequency information in the structured interview, did not translate to enhanced generate or recognition performance. Participants who volunteered low level knowledge on the structured interview are as likely to produce high level knowledge on the generate or recognition task as high performing structured interview participants.

The level of information volunteered in the structured interview did, however, predict to some degree the ratings given in the recognition test. Those individuals in the interview who gave higher level information did not show increased ability to discern foils from targets, but did rate all fragments as more 'recognised'. Thus, it would appear that greater ability to divulge information in the structured interview is an indication of confidence as opposed to level of explicit knowledge. This conclusion was also reached in the prior discussion regarding which information was learned explicitly. This finding also has parallels with work within the eyewitness testimony literature, which contends that confidence in eyewitness reports does not determine accuracy of the information given Wells and Murray, 1984).

Additionally, the generate and the recognition tests elicited more information from participants than did the structured interview. These two tests appeared to be more sensitive to explicit knowledge, and again this may be a function of the confidence and willingness to divulge information in the structured interview. The relative insensitivity of the structured interview should be taken into account before considering using it as a sole test of explicit knowledge. This is especially true when researchers rely on the apparent finding that participants have little or no explicit knowledge to conclude that implicit learning has occurred.

Whilst thus far the conclusion has been that the level of information given in the relatively insensitive structured interview does not predict performance on the remaining two direct tests, there is not total disagreement between direct tests. The structured interview may be insensitive and confounded with participant confidence in their explicit knowledge, but the agreement between the particular information volunteered in the structured interview and in the recognition or generate tasks is relatively impressive. This finding is reassuring as, confidence aside, these direct tests appear to be accessing the same knowledge. When information is volunteered in the structured interview, it is likely to be found embedded within the knowledge exhibited in the recognition and generate tasks.

One possible criticism of the direct tests used in this study is that the free generate and the recognition tasks are not tests of explicit knowledge, but are instead implicit in nature. This cannot be argued for the structured interview. It is considered to be a test of explicit knowledge. Yet the degree of overlap in the information given between the structured interview and the generate task, and the interview and the recognition test, suggests that they are measuring the same construct. The consistency in the information gathered from these tests goes some way to expelling this criticism.

What is concerning is that in recent sequence learning studies, researchers have been interested solely in whether any explicit learning occurred, and not in examining what information has been translated to explicit knowledge. It is in this latter information that the direct tests appear to most greatly agree. Disagreement seems most likely to occur between the results of these direct tests when using them as tools to determine if any explicit learning has occurred. Researchers may be wise to exercise caution in choosing any one particular direct test for this purpose. If having to limit the direct test to one, preference is displayed here in the generate task as it appears to provide the fullest picture of the extent and type of explicit knowledge if fully utilised.

4.5 Replication of Leadley's decision time-explicit knowledge link

Leadley (1997) posited that explicit sequence knowledge lead to prediction in the SRT which resulted in diminished decision times, whilst implicit learning was reflected in decreased movement times. To demonstrate this assertion Leadley (1997) used an apparatus different from that used in typical sequence learning studies with participants initiating their responses from, and returning to, a home key.

This study attempted not only to replicate Leadley's link between explicit knowledge and decision time, but also to generalise this finding to a new apparatus. The response apparatus utilised in this study could be considered as intermediate between the typical sequence learning apparatus and Leadley's home key version, thus bringing Leadley's (1997) procedure more in line with traditional sequence learning methods. In doing so, measurement of TRT and movement time in this experiment had to be sacrificed, as without a home key these measures may be confounded with the uneven distances between keys. To minimise this confounding influence, the allocation of sequence position to key location was randomised for each individual. As decision time was the main measurement of interest to this study in determining its relation to explicit knowledge, this decrease in the reliability of the TRT and movement time measures was not considered to be critical.

Despite the confound present in TRT, learning evidenced by TRT decreases for sequence participants, over that exhibited by random control participants, was expected. As outlined above, demonstrating learning in terms of TRT patterns was not central to this study. However, the absence of such an effect, given that the hoped for DT decreases did not occur, was of concern. At first glance, it would appear that the lack of both differential DT and TRT decreases for the training groups, indicate that sequence learning simply did not occur in this study. This conclusion would obviously be very damaging. Possible criticisms to this effect could be that the incorporation of a variable response-stimulus interval is disruptive to sequence learning (Stadler, 1993), or that the sequence used is low in statistical structure (Stadler, 1992) which makes sequence learning difficult. Alternatively one could assert that the use of a twelve-long sequence, as opposed to the typical ten-long sequence, made for a sequence learning context that was too complex for learning to occur. The fact that sequence participants were able to explicitly report structural sequence knowledge indicates that learning of the sequence did in fact occur, and negates the above potential criticisms.

The failure to uncover a training group difference for decision time over the eleven blocks of training in this study was very disconcerting. The rationale was that the sequence participants, at least, should have explicit knowledge that the random series participants could not have, resulting in decision time decreases for the sequence group. The direct tests of explicit knowledge illustrated that both the sequence and relative frequency controls possessed explicit knowledge, yet this knowledge appeared not to be reflected in decision time.

However, attempting to link decision time to explicit knowledge through the use of group comparisons is not ideal. Sensitivity to sequence manipulations is reduced when participants with and without explicit knowledge are present in each group. Individual differences need to be accommodated. Even so, no decision time link was found when comparing participants who did and did not demonstrate explicit knowledge.

Another tenet adhered to in this study, was the assumption that different participants might accumulate different explicit sequence knowledge. If Leadley's (1997) assertions are correct, then within each participant's SRT performance we may see dissociation between decision times for explicit and non-explicit sequence components. Even when this within-participant analysis was performed over all the participants in the study there was no evidence for reduced decision times corresponding to explicit knowledge.

This may be damaging to Leadley's (1997) proposed decision time- explicit knowledge link. However, doubts have arisen regarding the decision time measure used in the present study. The properties of the current unique procedure may have led to inadequacies. As noted above Leadley (1997) posits that a differential decline in decision time should occur for the different training groups. However, Leadley's (1997) theory also would predict a decline *only* if explicit knowledge were present. In this study, not only was there a failure to find a differential decision time pattern, but a decision time decrease over blocks occurred for all training groups. A decision time reduction by the random control participants suggests that the 'decision time' measure in this study was not pure.

Close examination of the decision times obtained in this study, reveal decision times as short as 150 ms. Whilst sensitive response switches, conducive to short decision times, were used, times as small as 150 ms suggest that participants may be initiating their responses before stimulus onset. When TRTs are analysed alongside DT, it appears that decision times are shortened at the expense of movement times for participants without the tone counting task. Taken together these results suggest that participants may be taking advantage of an anticipation strategy which may involve releasing the response key early to move toward the centre of the response key arc. This strategy would result in reduced response times only for stimuli that lie in the direction of this movement, with costly mid-flight corrections for the remaining response keys and these would outweigh the benefits of the anticipations. Analyses investigating TRT (minus DT) differences between movements to response keys in the direction of the centre of the arc and those that are counter this movement were considered time consuming without providing a valuable addition to this thesis. The short decision times, alongside the TRT pattern, are sufficient to suggest the likelihood that an anticipation strategy has been utilised.

This study involved explicit instructions regarding the importance of keeping the switches depressed until the next light appears, and error lights illuminated when this did not occur. A variable response-stimuli interval was also incorporated to lessen the likelihood that the time of onset of the next stimulus was predictable. Despite all attempts to discourage anticipation, it would appear that the decision time measure in this study may have been contaminated by a tendency for participants from all training groups to release their finger early, but not so early as to produce an anticipation response. Potential information regarding explicit knowledge, which may be gleaned from the decision time measure, may thereby have been masked.

The failure by this experiment to capture explicit knowledge expression in decision time may not necessarily reflect on the replicability of Leadley's (1997) findings. However, it is important that other researchers attempt to replicate and extend these assertions. This study has been useful in highlighting the possible difficulties that can be encountered with regard to response anticipation when attempting to measure decision time. Other attempts and strategies to prevent anticipation should be considered by the next researchers attempting to replicate Leadley's results. The unique apparatus used here may still be valuable in this endeavour, or in a later attempt to extend Leadley's (1997) findings to more closely resemble traditional sequence learning studies.

4.6 Concluding Remarks

In conclusion, this study makes a valuable contribution to the area of sequence learning in the following ways:

- The study highlights the importance of thorough investigations into the role of explicit knowledge in sequence learning studies, including ascertaining what information is amenable to conscious recollection. In doing so, attempts were made to challenge the assumptions, commonly in use in the area, relating to explicit knowledge.
- An individual within-participant, in-depth examination of explicit knowledge was introduced for the first time. This approach may prove to be more valuable than current practices in obtaining a full and accurate picture of the role of explicit knowledge.
- A demonstration of explicit knowledge of relative frequencies embedded within the sequence was achieved for structured control participants. This information can be learned explicitly, and is important and useful information in its own right.
- Contrary to current belief, stimuli reversals (such as ECE) do not appear to correlate with explicit knowledge.
- Sequence participants appear to exhibit the ability to recollect higher order sequence information, to the detriment of explicit frequency knowledge.
- Valuable insights are given into methodologies to avoid or consider for future attempts to replicate and extend Leadley's (1997) hypothesised link between decision time and explicit knowledge.
- The secondary task, frequently used in sequence learning studies, does not appear to diminish explicit knowledge as assumed, but instead seems to act by simply slowing participants by adding another task to complete.
- This study tentatively compares the results of the recognition, free generate, and structured interview direct tests. It was found that general agreement is reached regarding the type of knowledge learned, but not the extent of explicit knowledge. Sole reliance on any one direct test, and particularly sole reliance on the relatively insensitive interview, is not recommended and should be avoided if at all practicable.
- Numerous suggestions for future research are outlined, with more in-depth studies

investigating the role of explicit learning considered as vital to the sequence learning area.

5.0 REFERENCES

Bradshaw, C. M., Szabadi, E., & Bevan, P. (1979). The effect of punishment of free-operant choice in humans. *Journal of the Experimental Analysis of Behavior, 29,* 161-166.

Cohen, A, & Curran, T. (1993). On tasks, knowledge, correlations, and dissociations: Comment on Perruchet & Amorim (1992). *Journal of Experimental Psychology: Learning, Memory and Cognition, 19,* 17-30.

Cohen, A., Ivry, R. I., & Keele, S. W. (1990). Attention and structure in sequence learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 17-30.

Conger, R., & Killeen, P. (1974). Use of concurrent operants in small group research. *Pacific Sociological Review, 17,* 399-416.

Curran, T., & Keele, S. W. (1993). Attentional and nonattentional forms of sequence learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 19,* 189-202.

Frensch, P. A., Buchner, A., & Lin, J. (1994). Implicit learning of unique and ambiguous serial transitions in the presence and absence of a distractor task. *Journal of Experimental Psychology: Learning, Memory and Cognition, 20,* 567-584.

Heuer, H., & Schmidtke, V. (1996). Secondary-task effects of sequence learning. *Psychological Research, 59,* 119-133.

Jimenez, L., Mendez, C., & Cleeremans, A. (1996). Comparing direct and indirect measures of sequence learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22,* 948-969.

Johnson, N. F., Turner-Lyga, M., & Pettegrew, B. S. (1986). Part-whole relationships in the processing of small visual patterns. *Memory and Cognition, 14,* 5-16.

Jonides, J. (1995). Working memory and thinking. In: E. E. Smith & D. N. Osherson (Eds.), *An invitation to cognitive science: Volume 3, Thinking (2nd ed.).* Cambridge, MA: MIT Press.

Lewicki, P., Hill, T., & Bizot, E. (1988). Aquisition of procedural knowledge about a pattern of stimuli that cannot be articulated. *Cognitive Psychology, 20*, 24-37.

McDowall, J., Lustig, A., & Parkin, G. (1995). Indirect learning of event sequences: The effects of divided attention and stimulus continuity. *Canadian Journal of Experimental Psychology, 49,* 415-435.

Miller, G. A., Bruner, J. S., & Postman, L. (1954). Familiarity of letter sequences and tachistoscopic identification. *Journal of General Psychology, 50,* 129-139.

Nelson, T. O. (1978). Detecting small amounts of information in memory: Savings for nonrecognised items. *Journal of Experimental Psychology: Human Learning and Memory, 4,* 453-468.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19,* 1-32.

Perruchet, P., & Amorin, M. (1992). Conscious knowledge and changes in performance in sequence learning: Evidence against dissociation. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18,* 785-800.

Perruchet, P., Gallego, J., & Savy, I. (1990). A critical appraisal of the evidence for unconscious abstraction of deterministic rules in complex experimental situations. *Cognitive Psychology, 22,* 493-516.

Reed, J., & Johnson, P. (1994). Assessing implicit learning with indirect tests: Determining what is learned about sequence structure. *Journal of Experimental Psychology: Learning, Memory and Cognition, 20,* 585-594.

Shanks, D. R., Green, R. E. A., Kolodny, J. A. (1994). A critical examination of the evidence for nonconscious (implicit) learning. In: *Attention and performance XV: Conscious and nonconscious information processing,* ed C. Umilta & M. Moscovitch. MIT Press

Shanks, D. R., & St John, M. F. (1994). Characteristics of dissociable human learning systems. *Behavioral and Brain Sciences, 17,* 367-447.

Stadler, M. A. (1989). On learning complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 1061-1069.

Stadler, M. A. (1993). Implicit serial learning: Questions inspired by Hebb. *Memory and Cognition, 21,* 819-827.

Stadler, M. A. (1995). Role of attention in implicit learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 674-685.

Wells, G. L., & Murray, D. M. (1984). Eyewitness confidence. In: G. L. Wells & E. F. Loftus (Eds.), *Eyewitness testimony: Psychological perpectives,* New York: Cambridge University Press.

Willingham, D. B., Nissen, M. J., & Bullemer, P. (1989). On the development of procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 1047-1060.

6.0 APPENDICES

APPENDIX A:

CONSENT FORM:
SECONDARY TASKS AND REACHING TIMES:

I have read and understood the description of the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity wil be preserved. I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.

Signed:.. Date:...

APPENDIX B:

EXPERIMENT FOR JOLIE WILLS:
INFORMATION:

You are invited to participate as a participant in the research project **'secondary task and reaction times.'**

The aim of this project is to assess whether a distraction talk will decrease the speed and accuracy of depressing switches when lights are illuminated.

Your involvement in this project will involve: placing the <u>index finger from your writing hand</u> on one key and reaching to depress a key associated with an illuminated light, as quickly and accurately as possible. Different lights will illuminate one at a time and your job then is to press the appropriate switch. <u>Both speed and accuracy are equally important</u>. It is important to keep your finger depressed on each key until the next light appears, at which time you must press the appropriate button as quickly as possible. We cannot record the results if you release the keys early. When the key is released prematurely a red light at the top of the response apparatus will illuminate to alert you to the fact that you responded too early. It is important to avoid this happening. You will also be presented consistently with a short tone before each light is illuminated. You may be chosen to keep a running total of the high-pitched tones, while also performing the key-pressing task. It is important that should you lose count at any stage in the experiment, please approximate the total you think you may have had and then continue counting the high-pitched tones.

Stage One:

To begin with, you will be given a short period to practice the task of reaching to turn off the switches when the lights come on, and keep a running total of the high-pitched tones if you have been asked to do so. Place your index finger of your writing hand on a key of your choice to begin.

Stage two:

Next the experiment will begin. You will be required to depress the switches as in the practice task and will be required to again keep a running total of high-pitched tones if you did so in the previous stage of the experiment. After a period of time, the experiment will pause and you will be required to report the total of your running count if you were asked to keep one. When you are ready, place your finger back on a key of your choice and the experiment will then continue, with similar breaks where you may be required to report your total number of high-pitched tones to the experimenter.

Stage three:

You will then be asked some questions concerning the task you have completed in the experiment so far.

Stage four:

Similar to stage two, but instructions will be provided when you are ready to commence this stage.

The entire experiment is expected to take approximately 45 minutes.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent.

The project has been review by the University of Canterbury Human Ethics Committee.

The project is being carried out by Jolie Wills, who can be contacted at 364 2987 Ext 8085, or email; willsj@psych2.psyc.canterbury.ac.nz. I will be pleased to discuss any concerns you may have about participation in the project.

APPENDIX C:

STAGE FOUR INSTRUCTIONS:
GENERATE TASK:

The onset of lights you encountered earlier was not completely random, there was some plan as to which occurred when. This stage of the experiment is designed to assess your knowledge of this information. I understand that you may or may not be aware of this knowledge, but this task is particularly good at assessing whether you have any such knowledge. I just ask that you do your best.

You are required to produce a 60-long sequence of key-presses which are as close as possible to those experienced in the previous eleven blocks of trials. As you press the keys the light associated with it will illuminate. Please begin by placing the index finger of your writing hand on a key of your choice. You will be given the first two lights of your sequence and should respond to them as you did in the experiment and then continue by generating a light (and key-press) sequence 60-long which resembles that which you responded to during training. A tone will sound once all 60 key-presses have been performed. You will be required to perform this task twice.

APPENDIX D:

STAGE FOUR INSTRUCTIONS:
RECOGNITION TASK:

The onset of lights you encountered earlier was not completely random, there was some plan as to which occurred when. This stage of the experiment is designed to assess your knowledge of this information. I understand that you may or may not be aware of this knowledge, but this task is particularly good at assessing whether you have any such knowledge. I just ask that you do your best.

You will be presented with sub-sequences of four lights which may or may not have occurred in your training. You are required to respond to the lights as previously be pressing the associated key. Then you must indicate how familiar each sub-sequence is. This can be done by replying *'yes'* if you know that you have definitely encountered the sub-sequence during the experiment, *'no'* if you definitely did not encounter the sub-sequence earlier, and *'maybe'* if you are unsure. In the case of *'maybe'* then you will be asked to reply *'maybe yes'* or *'maybe no'*. You will be provided with a card to refer to with the possible answers and their meanings. You will be given two sessions of this task.

APPENDIX E:

EXPERIMENT FOR JOLIE WILLS:
DEBRIEFING SHEET:

The experiment you have just completed investigated implicit learning of a sequence. The concept of implicit learning basically means; 'learning without being aware of the nature of what it is that you are learning, or indeed without awareness that you are learning anything at all'. In this experiment you may have been exposed to a repeating sequence of lights, depending on which experimental condition you were assigned to. [Inform the participants here whether they belonged to the sequence or to a random or semi-random control condition]. Whether or not learning occurred in the sequence condition was assessed by looking at the reaction times of the subjects exposed to the sequence, compared to those exposed to a random or semi-random series of lights. If the reaction times are consistently shorter, then we conclude that learning has occurred.

The aim of this experiment was to assess which information in the sequence is explicit, that is which information you, the participant, are aware of. This was assessed by examining decision time, and testing to see which parts of the sequence could be recognised or generated. Explicit knowledge is reflected in decision time, as if you know where to move your finger before the light comes on (explicit knowledge) then you are able to remove your finger from the previous key more rapidly.

Feel free to ask any questions about the experiment. If you should have questions at a later time I can be contacted at ph 364 2987 Ext 8085, or via email at 'willsj@psych2.psyc.canterbury.ac.nz'

Thank you for you participation and co-operation in this experiment.